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On-wafer Monitoring Sensor for Precise Control of Plasma Processes
高精度プラズマプロセス用オンウエハーモニタリングセンサー

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We developed “on-wafer monitoring sensor”, such as, charge build-up sensor, sidewall conductivity sensor, photon radiation sensor and ion energy analyzer, for in-situ monitoring in plasma etching processes. By using these techniques, precise control of plasma processes and prediction of plasma radiation damages in processes could be realized.

1. Introduction

Gate insulator for metal-insulator silicon (MIS) devices needs high breakdown voltage, low leakage current and low interface states for robust semiconductor devices. During the fabrication of the MIS devices using plasma process, the amounts of the ultraviolet (UV) photon are irradiated to the gate insulators. In particular, the UV with wavelengths more than the band gap energy of the dielectric film can generate electron-hole pairs in the UV-irradiated dielectric films. This generation increases the charge densities trapped in dielectric film and in the interface [1], thus affecting the conductivity of the dielectric film layer [2,3]. Especially, the image of the charge-coupled devices (CCDs) was degradated by the UV photon radiations. Because the SiO_2 / Si interface state were generated by the UV photon radiation. The generation of the interface state density might caused by the generation of the electron-hole pairs in dielectric films [4]. Therefore, it is necessary to evaluate the generation of the electron-hole pairs in dielectric films during the plasma etching process to improve the reliability of the MIS devices.

However, it spends high costs a lot of time to evaluate the UV radiation damage by using the actual MSI devices. Thus, we proposed the “on-wafer monitoring” system for the evaluation of UV radiation damages by simple structure devices [5]. The on-wafer monitoring devices consist of only the insulator of the MIS devices, and it is easily to evaluate the UV radiation damage by measuring the “plasma-induced current” in insulator films during the plasma etching processes. We had already reported that the generation of the plasma-induced current depended on the UV wavelength that depends on the gas chemistry [5].

In this paper, we investigated the UV radiation damages by measuring the plasma-induced current in on-wafer monitoring devices with several insulator materials or structures. In addition, we evaluate the effect of the gas chemistry and compared with the damages in CCDs.

2. Experimental

2.1 Experimental setup

Figure 1 shows the experimental setup for the plasma irradiation. Applying 13.56 MHz RF power to one turn antenna generates CF_4/O_2, C_2F_4/O_2 and C_4F_8/O_2 inductively coupled plasma. We used ultraviolet (UV) spectrometer to measure UV light intensity. The flow ratio of the fluorocarbon gas verses oxygen were fixed at 50 sccm / 15 sccm under the 2.6 Pa gas pressure. The electron density were fixed at 5.5×10^{10} cm^{-3} by varying the RF power.

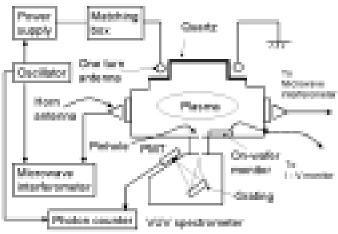

Fig. 1 Experimental setup. Plasma was irradiated upon on-wafer monitoring devices

2.2 On-wafer monitoring devices

To evaluate the plasma-induced electron-hole pairs in dielectric films, we used the on-wafer monitoring device. We made four kinds of devices. Every device has the polycrystalline- silicon (poly-Si) electrode (100 nm) on the thermal oxidized silicon substrate (SiO_2: 500 nm). Figure 2 a) shows the on-wafer monitoring devices with SiO2 film. The SiO_2 thickness was 150 nm on the poly-Si electrode. SiO_2 film was deposited on the poly-Si electrode by low pressure CVD (LP-CVD) process. In Figure 2 b) and c) , the dielectric film consist of the SiO_2 (75 nm)/Si_3N_4 (75 nm) and Si_3N_4 (75 nm) SiO_2 (75 nm) films, respectively. We irradiated the each gas plasma to these on-wafer monitoring devices and evaluated the generation of electron-hole pairs as “plasma-induced current” during the plasma etching process. Plasma-induced current is expected to increase when the UV lights were higher energy than the band gap energy of the dielectric films. The band gap energy of the SiO_2 and Si_3N_4 film are 8.8 eV and 5.0 eV, respectively. Therefore the plasma-induced current must depend on the kind and structure of the dielectric films. These plasma-induced currents were measured at the bias voltage of –30 V. The chamber had ground potential. The background current when turning off the plasma was less than 20pA.

3. Results and Discussion

Figure 3 shows the plasma-induced current in the dielectric film of SiO_2 , SiO_2/Si_3N_4 and Si_3N_4/SiO_2 . In the case of the Si_3N_4/SiO_2, the plasma induced current drastically reduced comparing with the film of SiO_2 and SiO_2/Si_3N_4. This result indicates that the generation of the electron-hole pairs in insulator depends on the substance and structure of the dielectric films.

In the case of the SiO_2 / Si_3N_4 structure, most ultraviolet photons of less than 140 nm were absorbed in SiO_2 film. However the UV lights of longer than 140 nm can be transmitted through the SiO_2 film because of the lower energy photon of less than the energy of SiO_2 band gap. Then the transmitted UV lights of shorter than 250 nm (5 eV, the band gap energy of the Si_3N_4 film) induce the electron-hole pairs in the Si_3N_4 film. As a result the plasma-induced current were generated.

On the other hand, in the case of the Si_3N_4 / SiO_2, most UV lights of less than 250 nm (higher than 5 eV) were absorbed at the Si_3N_4 film on the SiO_2. Because there are little UV light absorbed in the SiO_2 film can transmit the Si_3N_4 film, the electron-hole pairs in the SiO_2 film were hardly generated.

From this result, we found that the damage creation mechanism strongly depend on the structure of the insulator film.

In addition, we compared the plasma-induced damage of CCD image sensors. We investigated the dependence of gas-chemistry with the plasma-induced current in the on-wafer monitor devices. The insulator of the CCD image sensor consists of the Si_3N_4 on SiO_2 film [6]. Therefore, the plasma-induced current in the Si_3N_4/SiO_2 was investigated ,as shown in fig. 4. In the CCD image sensor, the dark current was increased with an increase in gas molecular weight [6]. The trends of dark current correspond to the plasma-induced current in the Si_3N_4/SiO_2 film. This means that the plasma-induced current and the CCD dark current in case of the C_4F_8 were larger than those in other gases.

This result indicates that the damages in CCD image sensor can be predicted by measuring the plasma-induced current. Moreover, we can control the damages in actual MIS devices with evaluating the plasma-induced current using a simple on-wafer monitoring device.

4. Conclusion

We evaluate the generation of the UV induced electron-hole pairs in MIS devices by using a simple on-wafer monitoring device. The generation of the electron-hole pair depends on not only the gas chemistry but also the structure of the insulators. This results were caused by the differences of band gap energy between dielectric films. This on-wafer monitoring devices is very effective for controlling the UV radiation damages in MIS devices such as CCD image sensors.

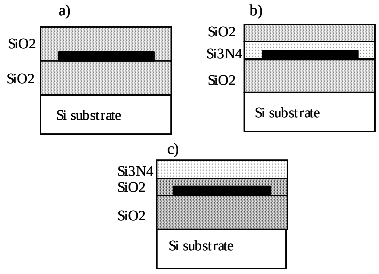

Fig.2 On-wafer monitoring device. Structure of the dielectric films consist of a) SiO_2, b) SiO_2 on Si_3N_4, c) Si_3N_4 on SiO_2.

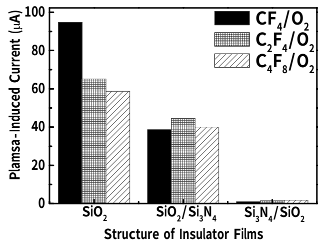

Fig.3 Plasma induced currents in SiO_2, SiO_2/Si_3N_4, and Si_3N_4/SiO_2 film.

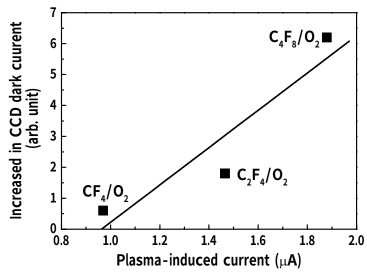

Fig. 4 Comparison between CCD dark current and plasma-induced current.

References

[1] T. Yunogami, T. Mizutani, K. Suzuki, and S. Nishimatsu : Jpn. J. Appl. Phys. 28 (1989) 2172.

[2] C. Cismaru, J. L. Shohet, and J. P. Mcvittie : Appl. Phys. Lett. 76 (2000) 2191.

[3] C. Cismaru and J. L. Shohet : J. Appl. Phys. 88 (2000) 1742.

[4] M. Okigawa, Y. Ishikawa, and S. Samukawa: Jpn. J. Appl. Phys. 28 (1989) 2172. Part 1 42 (2003) 2444.

[5] S. Samukawa, Y. Ishikawa, S. Kumagai, and M. Okigawa : Jpn. J. Appl. Phys. 40 (2001) L1346.

[6] Y. Ishikawa, M. Okigawa, Y. Ichihashi and S. Samukawa: IEDM Technical Digest (2003) 16.3.