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Impact of F Species on Plasma Charge Damage in a RF asher

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Abstract

Resist stripping and cleaning is evaluated on a RF asher. A combination of RF and MW power can be used to enhance the stripping efficiency in the asher. The RIE components of a plasma are capable of producing plasma damage (can be observed in structures such as thin gate oxide underneath poly lines). In this evaluation, both metal antenna structures and Charm-2 wafers were used to monitor plasma charging. No plasma charging was observed using the standard O_2/N_2H_2 plasma, but high plasma charge voltages could be observed with NF3 addition. The plasma characteristics were studied using optical emission spectroscopy. Analysis of the results suggests that plasma charging can be induced by a combination of RF and free fluorine species in the plasma.

Introduction

Oxygen plasma is widely used to ash photo resist. The plasma is usually generated by a microwave (MW) plasma or an inductive coupled plasma source [1] where plasma generation is remotely away from the wafers. Ionized species have shorter recombination lifetimes than neutral species. The majority of the ions will recombine with electrons and become neutral species before they reach the wafer [2]. Therefore, most down stream plasma sources show no plasma charge damage from ions. However, with hardened resist due to etch or implant process, the pure chemical components of the down stream plasma are less effective in stripping resist, RIE bombardment or a more reactive chemistry will improve the strip efficiency. In this paper, we will report on the usage of a combination of RF and MW for photo resist ashing and cleaning, and the effect of the RIE components of plasma on plasma charging. In particular, we will study the effect of C_xF_y and NF_3 chemistries on plasma charging in the RIE plasma.

Experimental details

An asher with dual RF and MW power source was employed for this study. The process gases (O_2, N_2:H_2, C_xF_y, NF3 etc) are supplied from the side of chamber. The gases are excited in the MW applicator, located on the chamber side wall before entering the process chamber (as shown in Fig. 1). A quartz baffle will redistribute the gas flow inside the chamber, so that the species distribution on the wafer is more uniform. A RF power is supplied to the bottom electrode to generate RIE bombardment. The wafer is placed on top of the bottom electrode, which can be heated up to an elevated temperature up to 300 C.

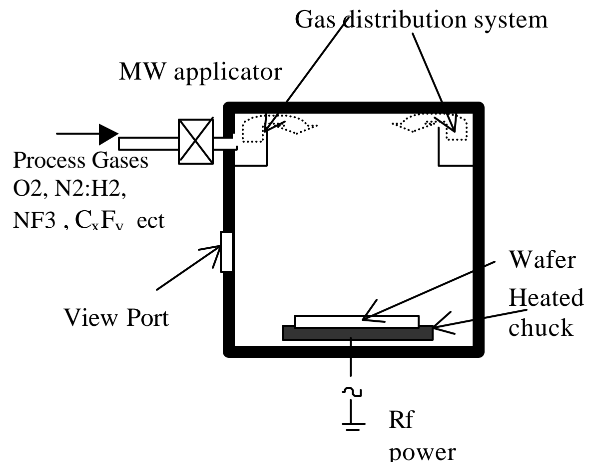


Fig. 1 Schematic of the asher with dual RF and MW power source

Optical emission from the plasma can be collected through a view port on the chamber sidewall, which is analyzed by an Ocean-Optic spectrometer.

Results and Analysis

In this study, the ash was primarily used for back end of line metal and via ash and cleans. Post via etch, there is a layer of harden polymer on the sidewall of the vias and on the

top of the photo resist. An $O_2/N_2:H_2$ RF/MW plasma exhibited high efficiency to ash the harden resist. An addition of NF_3 (or C_xF_y) to the plasma converts some polymer to become water soluble. In addition, the F in the plasma can attack some SiO_2 which would loosen up the polymer. For metal lines, Cl_2 and BCl_3 are used to etch TiN/Al. Post metal etch, there is $AlCl_x$ based polymer on the metal sidewalls which is not water soluble. The F plasma can also replace the Cl in the polymer, which will also make this polymer water soluble [3]. Post ashing, the wafers are rinsed through a spin rinse dryer. SEM images show that the bottom of via is free of polymer. Lots with 200 mm diameter device wafers were run through the production line with splits between the new solvent free ash/clean process and the baseline solvent clean process, the new process showed comparable sort yield and via resistance to the baseline process[4].

To evaluate the plasma charge in line, device wafers with gate oxide thickness ranging from 60 to 110 A were used. Metal antennas at every metal level are connected to the testing poly gate. The antenna ratio of metal/via to poly ranges from 30 up to 1000. The charge current within the plasma will be collected through the metal antenna and be transferred to the gate oxide. If a sufficient charge is conducted to the gate, a large shift of the transistor threshold voltage (VT) would be observed. If a high level of damage was done to the gate oxide, the transistor would show high leakage.

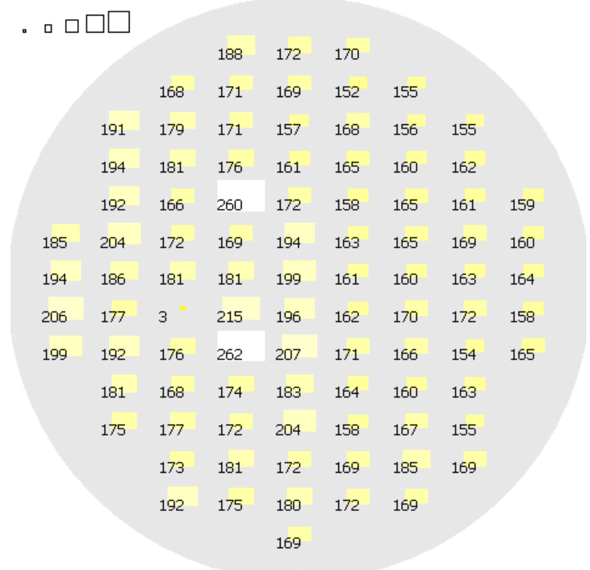
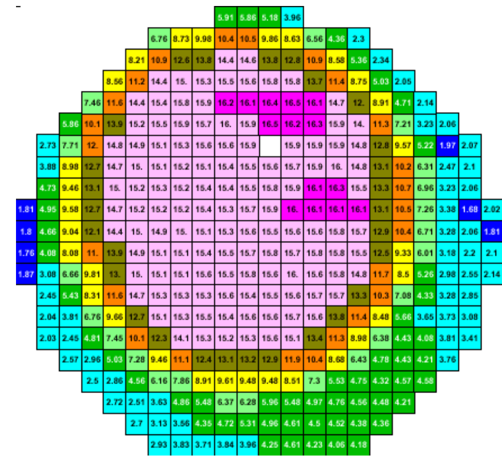


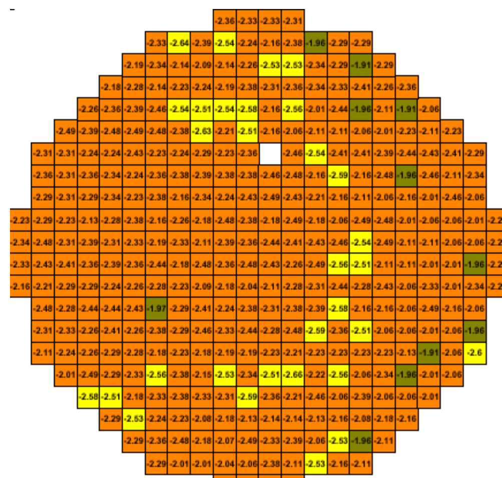
Fig. 2 VT shift map on wafers run through dry ash/clean process with a RF/MW O2/N2:H2/NF3 plasma on all levels of metal and via.

The baseline solvent clean wafers showed the VT shift <100mV. For the wafers cleaned with $O_2/N_2:H_2/NF_3$ RF/MW plasma for both metal and via cleans, large VT shifts up to 260mV are observed on the wafer center, as shown in Fig. 2. This high VT shift also results in high gate oxide leakage. In comparison to the solvent clean process, the plasma does exhibit charge damage to device wafers on the wafer center. However, if only via is exposed to this plasma, only a minimum amount of VT shift is observed.

To quantify the plasma charge of the various plasma conditions, CHARM-2 (Charge Monitor-second Generation) wafers are used to monitor the plasma charge. In the Charm wafers [5,6], metal antennas collect plasma charge and store it in EEPROM gates. The charge develops a voltage across the gate and substrate capacitor, which changes the Vt of the EEPROM transistor. Through the Vt shift test, both negative and positive plasma potentials can be probed. In addition, the charge flux can also be detected by the voltage drop across the resistor in Charm wafers. The impact of plasma charge on gate oxide integrity is a strong function of gate oxide quality and the design of the device. For 50-70 A thick gate oxide, any plasma voltage >= 6V will potentially impact the gate oxide integrity.



(a)



(b)

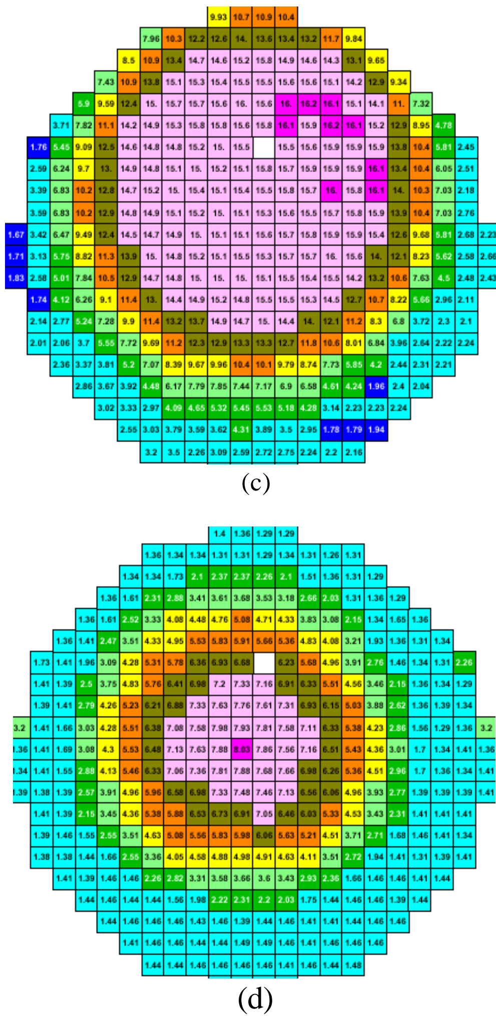


Fig 3 Charm-2 positive voltage wafer map of different plasmas: (a) O_2/N_2:H_2/NF_3 RF/MW plasma; (b) O_2/N_2:H_2 /C_xF_y RF only plasma; (c) O_2/N_2:H_2/NF_3 RF only plasma; (d) O_2/N_2:H_2 /C_xF_y RF/MW plasma.

An O_2/N_2:H_2/NF_3 plasma running both RF and MW shows a high plasma voltages >15 V positive potentials at the center of the wafer, as shown in fig. 3a. However, the plasma current of this plasma at voltage >6 V is relatively low (~50 uA/cm^2). Because the via size is very small, the total area exposed to the plasma during ash relative to the area of metal line is also small. Therefore, the plasma current collected to gate during ashing will be also very small. A via ash process would exhibit much lower level charge damage than a metal ash process. Although the plasma charge voltage is high for this plasma, the plasma damage during via ash will be minimal with the low plasma current, which is consistent with the VT shift data on device wafers.

The RF component in the plasma does not always generate high plasma charge. When NF_3 is removed from the plasma, the CHARM-2 wafer exhibits plasma charge voltage less than 4 V for the RF/MW plasma of O_2/N_2:H_2 . The combination of F containing gas and RF does not always generate high plasma charge either. The CHARM-2 wafer of O_2/N_2:H_2 /C_xF_y RF plasma also exhibits plasma voltage <4 V, as shown in fig 3b. However, the RF only plasma of O_2/N_2:H_2/NF_3 does exhibit plasma voltage of >15 V (fig. 3c), but the overall plasma current is lower than the O_2/N_2:H_2/NF_3 RF/MW plasma. Therefore the plasma charge is sensitive to both RF and the chemistry of gas being used. In addition, the plasma charge is also sensitive to how the plasma is generated. When MW power is added the O_2/N_2:H_2/ C_xF_y RF plasma, medium level of charge voltage (8 V) is observed.

To understand the mechanism of plasma charge, the above plasmas have been analyzed by optical spectroscopy. Fig. 4 shows the emission spectrum of the O_2/N_2:H_2 RF plasma from 380 to 850 nm. Emission peaks of O, O2+, N, N2, H, H2O, OH have been observed in the spectrum. After MW power is introduced, a broad emission from ~500 to 700 nm is observed. When NF3 is added to the above plasma, the overall density of the plasma increases, as shown in Fig. 4.

To compare the optical intensity quantitatively using a spectrometer, the plasma process conditions i.e. O_2/N_2:H_2 flows, pressure, RF power, MW power and the settings of the spectrometer were the same for all spectra. Reference spectra of O_2/N_2:H_2 RF plasma were taken at the beginning and the end of collection of different spectrum, no drift of the system has been observed. The net emission contribution of the F based chemistry to the RF power only plasma can be obtained by subtracting the emission intensities for both the C_xF_v based RF

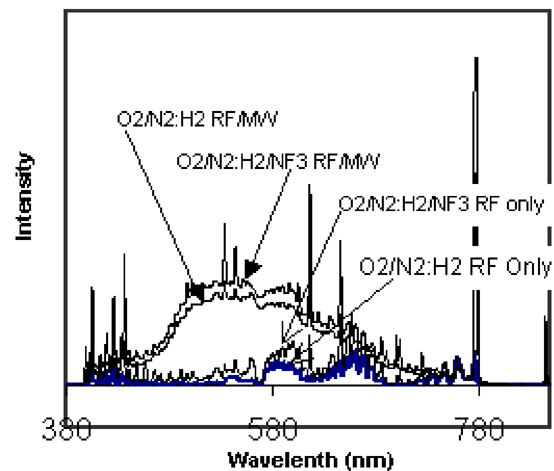


Fig. 4 Emission spectra of the O_2/N_2:H_2 RF only plasma, RF/MW plasma and O_2/N_2:H_2/NF_3 RF only and RF/MW plasma.

plasma ($O_2/N_2:H_2$ / C_xF_y) and the NF3 based RF plasma ($O_2/N_2:H_2$ /NF_3) from the baseline RF process ($O_2/N_2:H_2$). A similar approach can be used for the Microwave/RF combination plasma to calculate the net contribution from the addition of Fluorine based chemistries. The net contribution of F based chemistries to the plasma is shown in Fig. 5.

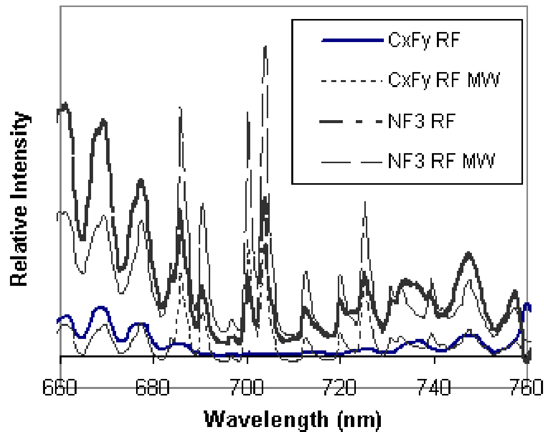


Fig. 5 The net emission spectrum of C_xF_y addition RF only, C_xF_y addition RF/MW, NF3 addition only and NF3 addition RF/MW plasma after subtract the base O2/N2:H2 spectra.

When NF3 or C_xF_y is added to the $O_2/N_2:H_2$ plasma, the O2, N2 emission density increases for all cases, as shown in Fig. 5. For $O_2/N_2:H_2$ / C_xF_y RF only plasma, no free F peaks have been observed. When MW is added to the above plasma, new emission peaks at 691, 700, 704, 713, 720 and 758 nm are observed. These peaks are identified with free F. When C_xF_y passes the MW applicator, MW power will break C_xF_y into F and other $C_{x-m}F_{y-n}$. The RF power is less effective in breaking C_xF_y bonds to form free F. NF_3 on the other hand is much more easier gas to dissociate in a plasma. The free F emission intensity of $O_2/N_2:H_2$ /NF_3 RF only plasma is stronger than $O_2/N_2:H_2$ / C_xF_y plasma with RF and MW. The $O_2/N_2:H_2$ /NF_3 RF/MW plasma exhibits the strongest free F emission intensity. The CHARM-2 wafers show high plasma charge voltage for all three plasma that exhibited free fluorine emission. In addition, no plasma charge voltage was observed on the $O_2/N_2:H_2$ / C_xF_y RF plasma using the Charm-2 approach which is consistent with no free Fluorine emission as observed by optical spectroscopy. This suggests that the plasma charge is sensitive to the combination of RF and density of free F species.

Summary

Plasma charge using RF/MW plasma combination was studied. Plasma charge was not detected for $O_2/N_2:H_2$ RF/MW plasma. With the introduction of NF_3 to the plasma high charge voltage and low charge current was probed on Charm-2 wafers. Plasma charge voltage detected on Charm-2 wafers increased monotonically with free F emission intensity as detected by optical spectroscopy. The results suggest that the plasma charge is a combination of RIE and free F within the plasma.

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REFERENCES

1. Stephen Savas, *Proceeding of the 1st International Symposium on Plasma Process-Induced Damage,* May 13-14, 1996
2. J. Shi, M. Kamarehi, D. Shaner, S. Rounds, S. Fink and D. Ferris, Solid State Technology, 44 (Oct. 1995)
3. Doug Dopp, Lisa Mikus, Amanda Horn, Richard Bersin, Han Xu and Mohamed Boumerzoug, *the197th ECS meeting, Toronto*, May, 2000
4. S.Q. Gu et al, *Proceeding of Semiconductor Technology (ISTC 2001)* p. 589, v.2
5. Wes Lukaszek, Solid State Technology, 101 (JUNE, 1998)
6. W. Lukaszek et al., *Proceedings of the International Symposium PI2D*, p200 (1999)