Effects of Processing Pressure on Device Damage in RF Biased ECR CVD

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Abstract

Charging effects were investigated in an Electron Cyclotron Resonance (ECR) Plasma-Enhanced CVD system using a variety of techniques including CHARM®-2 wafers[1,2], SPORT wafers[3] and full device antenna structures. In this work we show two factors affecting potential at the surface of the wafer which can be correlated to conditions where severe plasma damage is expected to occur. The CHARM-2 wafer data detected both the time-averaged (DC) and time-varying (AC) potentials. The DC component is shown to be a function of the applied wafer bias power while the AC component appears to be related to a low frequency potential fluctuation (a possible instability in the microwave generated magnetized plasma). Both of these signals can be reduced by increasing the processing pressure. Processes with higher pressure results in improved device damage immunity.

I. Introduction

Charging in an RF biased ECR-CVD processing equipment has been investigated by a number of groups. Various mechanisms including non-uniformity in ion and electron currents or magnetic flux have been suggested as causes for charge induced device degradation[4-6]. Similar evidence has been shown by researchers using biased ECR for etching purposes as well[7-9].

In this work, we show evidence for two new sources of high induced surface potential that may contribute to damage. One is an apparent interaction of the applied RF bias with the magnetized plasma and the other is a result of a low frequency time-varying surface potential that may be related to an observed fluctuation in the microwave generated plasma. We also show that increased processing pressure reduces both of these surface potentials and increases actual device yield.

II. Experiment

From an equipment vendor's point of view, obtaining device wafers for the study of plasma induced damage can be costly, and turn around time is very slow. For this reason we have employed CHARM-2[1,2] and SPORT[3] monitoring techniques for measuring the potentials that can develop on wafer surfaces. Turn around time for experiments is reduced from days and weeks to hours. CHARM®-2 wafers employ full wafer arrays of EEPROMs to measure peak positive and negative voltages. The data reported here has been screened

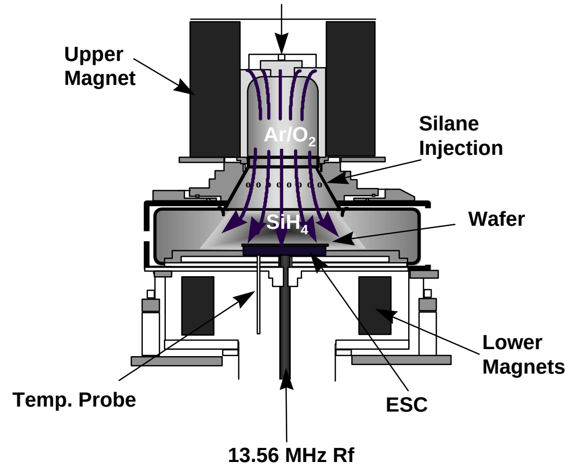

Fig. 1. Cross sectional diagram of the ECR-CVD chamber used in this work.

for current densities (typically >1mA/cm^2) that could damage thin gate oxides. The CHARM-2 wafers were subjected to depositing processes for 30 seconds resulting in silicon dioxide films approximately 350nm thick. The wafer was subsequently dipped in buffered oxide etch to remove the oxide before measuring the EEPROM characteristics. We found that the CHARM-2 wafers could survive 20 depositions if over etch was minimized.

The SPORT wafer was used without low bandpass filters. Only non-RF biased conditions were investigated. Because this technique lends itself solely to non-depositing conditions, the data reported is for oxygen/argon plasmas only. The voltage on the pad (an exposed plate of aluminum separated from the substrate by 100nm of silicon dioxide) was measured relative to the grounded substrate.

The ECR CVD system used (see fig.1) is described in detail elsewhere[10]. The system employs a NTT type ECR source using 2.45 GHz microwave frequency. The wafer is RF biased up to a power density of 8 W/cm^2 at 13.56 MHz for typical gap fill applications[11]. The 200mm wafers are held in place by a monopolar electrostatic chuck which uses backside helium for real-time temperature control. The magnetic field shape and strength is controlled by varying the currents through three independent magnets, one situated around the source and two just below the wafer. For the investigations reported here these magnets were set such that the magnetic field was uniform and nearly normal to the wafer surface. Typical deposition conditions used 100 sccm O_2, 40 sccm Ar, and 80 sccm SiH_4 flows. Depositions were performed at pressures between 2 and 10mT.

III. Low Pressure (2mT) Results

Figure 2 shows maps of positive peak potential responses recorded by the CHARM-2 wafer after being exposed to 30 seconds of deposition. Figure 2a shows the case with no RF (microwave power only), and Fig. 2b with RF bias (8W/cm^2) applied to the wafer. For simplified analysis purposes we have extracted a smoothed diametric line scan representation of the data, which is justified because the data is azimuthally symmetric.

Figure 3 shows both the positive and negative line scan data for the unbiased and biased cases. The most obvious feature is a severely non-uniform peak potential associated with the application of RF power. Highest positive peak potentials are found in the center while highest negative peak potentials are found at the wafer edge. Potential non-uniformities of this magnitude will damage semiconductor devices. Similar studies with medium sized (~1000:1) antenna structures on device wafers with 5nm gate oxide showed the yield decreased from 100% to around 50% with RF bias. A second more subtle effect shows up even in the no RF bias case. Figure 4 shows the zero bias data plotted on a magnified scale so that the details are more evident. Both positive and negative potential responses are detected toward the edges of the wafer, while the center is below the threshold level (the hashing indicates the region of no detectable response). This effect can also be found buried in the RF biased case in fig 3. While maximum positive peak voltages are

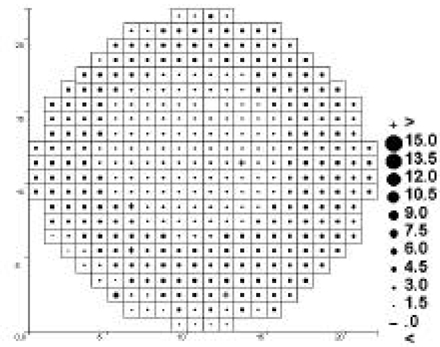

Fig. 2a. Positive voltage response after exposure to microwave only (no RF bias) deposition.

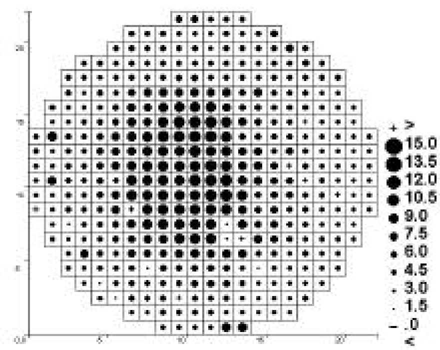

Fig. 2b. Positive voltage response after exposure to biased deposition (i.e., a gap fill process).

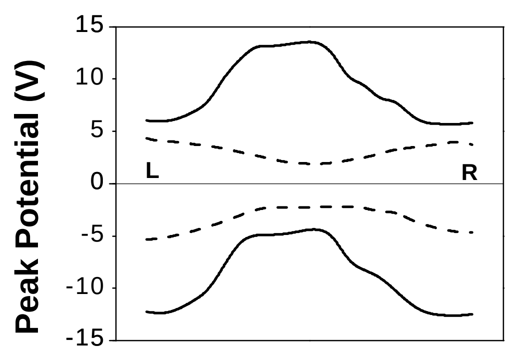

Fig. 3. CHARM®-2 Positive and negative voltage response after exposure to zero biased deposition (dashed line) and RF biased deposition (solid line).

observed in the center, we also see negative peak responses above threshold. Similarly, significant positive peak signals are detected at the edge, where the maximum negative peak potentials are observed. Note that with RF applied the positive and negative potential curves have very similar shape, positive peak in the center, negative peak near the edges, whereas the zero bias case shows both polarities peak at the same spatial positions near the edges.

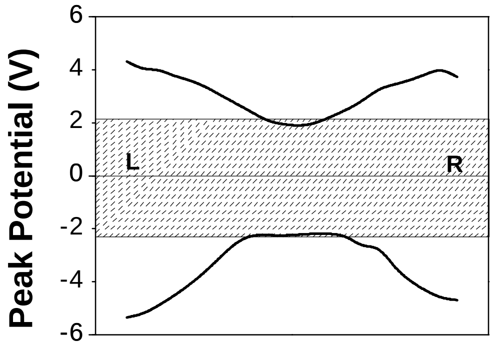

Fig. 4. CHARM®-2 Positive and negative voltage response after exposure to zero biased deposition. The hashed region indicates the threshold level.

IV. Effect of Increased Pressure

To reduce the surface potentials seen by the wafer, the process pressure was increased. Figure 5 shows the maximum peak voltages (at the 95% level of the cumulative distribution) for three processes run at different pressures. Both positive and negative voltages were reduced by more than a factor of 3 when the pressure was increased to 10mT.

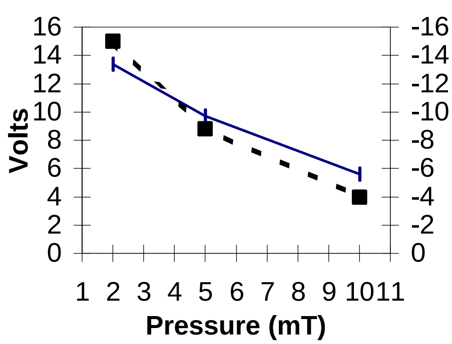

Fig. 5. CHARM®-2 maximum peak voltage responses (solid for positive and dashed for negative) after exposure to 30 second high biased depositions as a function of process pressure.

Figure 6 shows the affect of pressure on positive and negative peak potentials for two wafers exposed to mcrowave only (zero biased) oxygen/argon plasma at different process pressures; 2mT and 10mT. Increasing pressure to 10mT nearly eliminates the existence of the response signals. A slight positive peak response is detected at the edge while the negative response is completely below threshold.

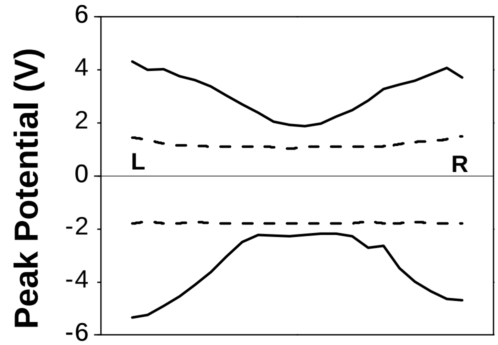

Fig. 6. CHARM®-2 Positive and negative voltage responses after exposure to zero bias plasma at 2mT (solid line) and 10mT (dashed line). Note that the wafer used for 10mT case had a lower threshold.

SPORT wafer measurements were carried out to obtain dynamic information about the potentials at the wafer surface. These measurements showed an oscillation of the pad voltage that had a frequency around 30kHz as measured by a spectrum analyzer. Figure 7 shows an example of the data signal versus time for two different pressures. The peak-to-peak voltage decreases as pressure is increased.

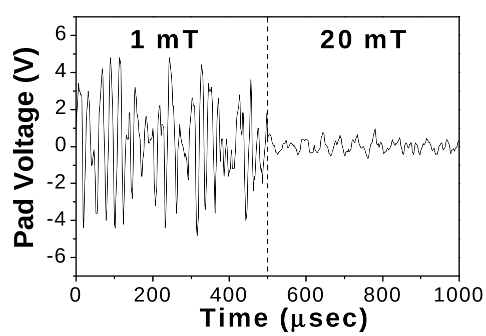

Fig. 7. Voltage signals on a SPORT wafer show a frequency of about 30kHz for a zero biased ECR oxygen/argon plasma at 1 and 20 millitorr.

V. Discussion

EEPROMs on CHARM-2 wafers serve as peak detectors for positive and negative voltages that develop across devices with complex (frequency dependent) impedance[1,2]. Because these devices have very low impedance at high frequencies, the EEPROMs do not register high frequency signals such as the usual quiescent plasma oscillations (typically in the GHz range), or even the RF signal at 13.56 MHz. Hence, unpatterned CHARM-2 wafers have been primarily used to study plasma density and other non-uniformity effects[12] which even in an RF driven sheath can show up as time-averaged non-uniformity in sheath potential variation. In such a case, each device on a CHARM-2 wafer registers the local voltage drop with respect to the local substrate potential. In the absence of significant lateral current flow, the substrate may be considered an equi-potential averaged over the wafer. Therefore, peak positive voltage detectors register values (higher than threshold) on dies that experience a lower sheath voltage drop, and conversely for the peak negative voltage detectors.

However, peak voltage excursions due to low frequency (kHz range) plasma fluctuation signals can be registered on the EEPROMs. At low frequencies, detection sensitivity is enhanced because the devices have high enough capacitive impedance relative to the plasma source to sustain a voltage above the threshold. These AC voltages can be registered by both peak positive and negative voltage sensors on the same die, as shown by the results in Fig. 4 and 6, which would be inconsistent with a DC signal. SPORT wafer measurements showed the frequency spectrum to be centered around 30kHz. Further work would be required to identify the specific origins of the fluctuations in the plasma, however magnetized plasmas can typically exhibit numerous low frequency plasma instabilities[13].

Increasing the processing pressure increases the collision frequencies which damps the low frequency plasma signals, as seen in Fig.7. The same decrease in the signal magnitude was also seen on the CHARM-2 wafers, as shown in Fig. 6.

With RF applied, the large center to edge DC potential variation, superimposed on top of the smaller time-varying component, was not seen to correlate with any significant plasma density non-uniformity as measured by a Langmuir probe. This center to edge variation is proably due to non-uniform RF coupling to the plasma in conjunction with the presence of a large magnetic field at the wafer causing cross field isolation.

VI. Conclusion

The effect of pressure on biased ECR CVD for gap fill application was investigated using CHARM-2 and SPORT monitoring techniques. The existence of both time-averaged (DC) and time-varying (AC) component of the induced surface potential were found. Increasing the pressure was seen to reduce the charging voltages. A new process was developed at higher pressure for a 0.25 micron technology employing 6nm gate oxide. The yield of a 20k:1 antenna ratio device was increased from 30% to 100%.

Acknowledgments

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