1997 2nd International Symposium on Plasma Process-Induced Damage
May 13-14, Monterey, CA

Study of Pattern Dependent Charging in a High-density, Inductively Coupled Metal Etcher

Roger Patrick and Phillip Jones
Lam Research Corporation,
Fremont, CA 94538

Wes Lukaszek
Wafer Charging Monitors, Inc.,
Woodside, CA 94062

Jeffrey Shields and Andrew Birrell
Microchip Technology,
Chandler, AZ 85224

Introduction

It is becoming increasingly evident that pattern dependent charging or electron shading is a significant charging mechanism for high density plasma etch systems. This mechanism, described by Hashimoto [1,2], can occur in uniform plasmas and is caused by the difference in isotropy of electrons and ions crossing the plasma sheath to the wafer surface. As electrons and ions interact differently with closely spaced structures on the surface of the wafer this leads to a differential charging of the structure with the top charging more negatively than the bottom. In this paper the voltages and currents developed by electron shading at the wafer surface are measured directly using a modified CHARM wafer.

Experiment

The use of CHARM wafers to monitor global wafer charging in plasma etchers and other equipment has been described before [3,4].

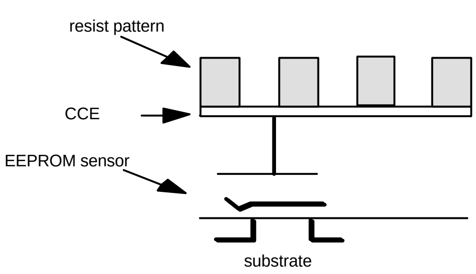

Figure 1. Modified CHARM design

The modification used here to detect pattern dependent charging was to add a photoresist mask with narrow lines and spaces over the charge collection electrodes (CCE) of the EEPROM sensors. Both the potential and the current sensors were modified in this way to allow both the voltage caused by electron shading and the current drawn from the plasma to be measured.

The layout was such that one die in four had a resist pattern with 1 micron lines and spaces arranged in a checker board pattern, the other dies were completely covered with photoresist. There were 470 line/space pairs on the patterned die each 210 µm long giving an effective charge flux collection area of 98,700 μ^2 and a total edge of 19.8 cm. The photoresist thickness was 1.1 microns.

Three experiments were conducted in a Lam TCP 9600 SE high density metal etch system. In the first case, a resist patterned wafer was exposed to a non-etching Ar plasma using 400 W TCP power at a pressure of 20 mT and 100 sccm flow with no wafer bias for 60s. In the second case the CCE metal stack, consisting of a sandwich structure with 250Å $MoSi_2$ on 1 micron Al-Si-Cu on 250 Å $MoSi_2$, was etched to completion using a standard BCl_3/Cl_2 process at 12 mT with 350 W TCP power and 132 W bias power. The total etch time here was 96s. In the final case, the same Ar plasma condition was used as before, except that a RF wafer bias was applied to give the same dc bias, around -130 V, as the metal etching case.

Results and discussion

Ar plasma case (no wafer bias)

Figure 2 shows the data from the positive voltage sensors. It can be seen that the baseline voltage response from the resist covered sensors is about 1.7 V while the voltage response from the patterned structures is higher at around 3.0 V

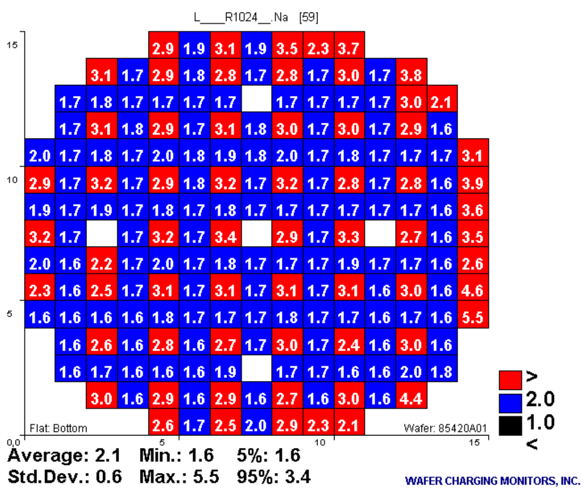

Figure 2. Positive voltage response seen after exposure to Ar plasma with no RF bias

Figure 3 shows the voltage response of the negative voltage sensors which is uniformly around -1.8 V with no difference between the patterned and unpatterned structures. These results are consistent with an electron shading mechanism which would predict that the charging at the foot of the resist structure would be positive in sign.

The current response for some of the patterned sensors is shown in the current-voltage (JV) characteristics given in figure 4 for two dies at the center of the wafer and three dies at the right hand edge.

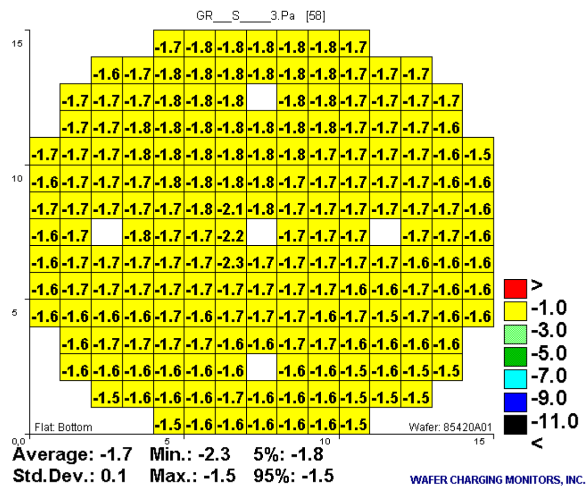

Figure 3. Negative voltage response seen after exposure to Ar plasma with no RF bias

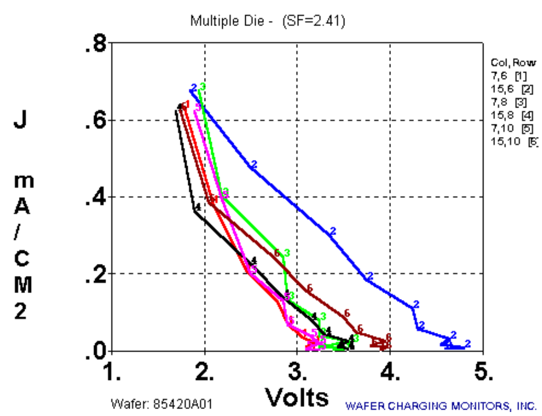

Figure 4. JV plot for Ar plasma exposure case with dc bias case taken for three dies at the center and two dies at the edge of the wafer

BCl_3/Cl_2 plasma case

The positive voltage sensor data from the wafer where the metal charge collector pads were etched to completion is shown in figure 5. In this case the potentials are higher than in the previous case with an average of around 7.4 Volts with some values up to 14 V. As in the previous case the negative potential sensors do not show any response. The corresponding JV data is given in figure 6 for two dies at the center of the wafer and three dies at the right hand edge.

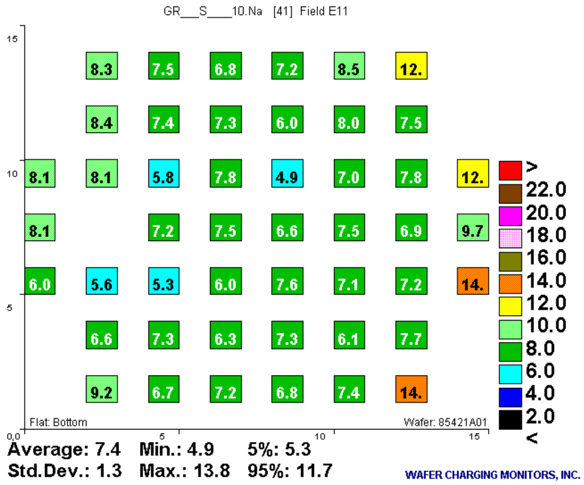

Figure 5. Positive voltage response seen after etching CCE with a BCl_3/Cl_2 discharge

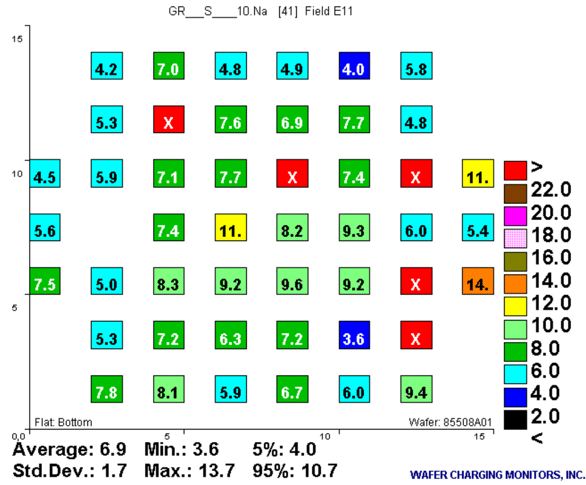

Figure 7. Positive voltage response seen after exposure to Ar plasma with RF bias

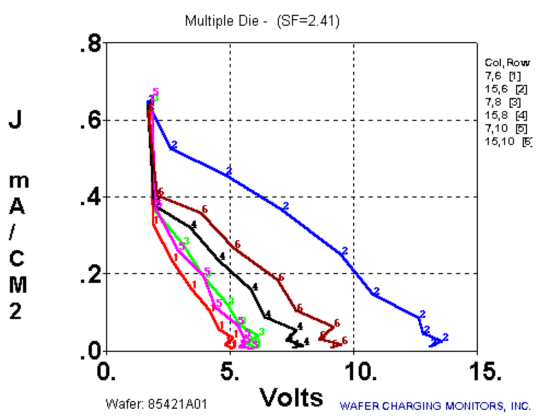

Figure 6. JV plot for BCl_3/Cl_2 etching case taken for two dies at the center and three dies at the edge of the wafer

Ar plasma case (wafer bias)

Figure 7 shows the data from the positive voltage sensors for the case where the wafer was exposed to the Ar plasma and also biased to -130 V. In this case the voltages are higher than those seen previously for the unbiased case and are similar to those seen for the metal etching case with an average voltage of 6.9 V and some values up to 14 V.

This shows that the dc bias or ion energy is important in determining the charging voltage a particular structure will reach and this appears to be more important than the process chemistry.

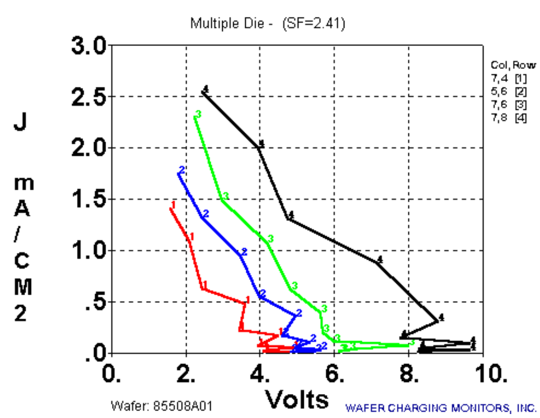

Figure 7. JV plot for Ar plasma exposure case with dc bias case taken for two dies at the center and two dies at the edge of the wafer

The corresponding JV data is given in figure 6 for two dies at the center of the wafer and two dies at the right hand edge.

The currents drawn in this case are substantially higher than in the metal etching case for equivalent charging voltages. This is consistent with the observation that the plasma density is about 4 times higher for the Ar process condition compared to the BCl_3/Cl_2 process [6].

Conclusion

It has been shown before [5,6] that for a bare CHARM wafer exposed to either an Ar plasma or a metal etching process in a TCP 9600 SE etcher, the charging response is minor. This indicates that whatever plasma non-uniformities there are in the system, they are insufficient to cause significant global wafer charging.

However plasma damage effects have been seen in such etchers using antenna wafers [7,8], especially where the antenna structures are perimeter intensive with narrowly spaced lines. The work described here uses CHARM wafers which have been modified to incorporate a resist mask on the charge collection electrode with narrowly spaced lines. In this case significant charging was now observed suggesting that an electron shading mechanism is operative.

This result explains the apparent discrepancy between the responses from antenna wafers and bare CHARM wafers.

The charging potential attained by a structure depends on the dc bias which in turn controls the energy of the ions crossing the plasma sheath to the wafer surface.

Under equivalent wafer bias conditions, the charging voltage measured with patterned CHARM wafers is the same for both etching and non-etching conditions. However the current drawn from the plasma for a given charging voltage has been shown to depend on the plasma density being higher for the Ar plasma studied here than the BCl_3/Cl_2 process.

References

1. K. Hashimoto, Jpn. J. Appl. Phys 32, 6109 (1993)

2. K Hashimoto, Jpn. J. Appl. Phys. 33, 6013 (1994)

3. W. Lukaszek et al., *Proceedings of the IEEE International Reliability Physics Symposium*, p334, (1994)

4. J. Schideler at al, Semiconductor International, 8, 153 (1995)

5. R. Patrick and P. Jones, Proc. 1st Int. Symp. Plasma Process Induced Damage
91 (1996)

6. R. Patrick, P. Jones and W. En, Proc. 2nd Int. Symp. Plasma Process Induced Damage (1997)

7. S. Krishnan et al, Tech. Digest IEDM, 315 (1995)

8. S. Krishnan et al, Tech. Digest IEDM, 731 (1996)