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Utility of CHARM® -2 in Diagnosing Sources of Plasma Charging Damage in High Density Etchers and in Assisting Hardware Development

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Introduction

In the early years of plasma damage history, much of the focus was on plasma non-uniformity issues (1). With little understanding of electron shading, many etch related damage issues were diagnosed by placing a CHARM-2 in the etch chamber, running a process and seeing if there was a signal. With high density plasma etchers, typically CHARM-2 would show no signal, though it was suspected that some type of charging damage was taking place. As the understanding of the role of electron shading in plasma charging damage became clear (2), the role of CHARM-2 in detecting plasma damage issues in high density etchers diminished.

CHARM-2 was not originally designed to be sensitive to electron shading type effects. The electron shading mechanism requires the presence of photoresist or some insulating layer on top of conductive lines to shade the electrons. CHARM-2 only has metal antennas. Some tests were done with post patterning of CHARM-2 wafers (3), but the cumbersome logistics made this type of testing impractical for most uses.

CHARM-2 though, still has an important role in diagnosing plasma charging issues in high density plasma etchers. To properly use CHARM-2, it is critical to understand what CHARM-2 is measuring and to understand how relevant that measurement is to a proposed charge up mechanism.

What is CHARM-2 and what can it detect?

CHARM-2 wafers incorporate wafer level ultraviolet (UV) sensors, potential sensors, and charge flux sensors in each die. The potential sensors are flash EEPROM transistors that measure the potential drop between a wafer level antenna and the substrate. The charge flux sensors are potential sensors that measure the potential drop across a known resistor. The sensors are first programmed to a maximum threshold voltage state, exposed to a charging source, then remeasured, and the difference (minus any leakage effects) is attributed to the charging phenomena. The utility of CHARM-2 is that the wafer can be reused until the probe pads wear out. A more complete and detailed description of CHARM-2 can be found in the CHARM-2 technical notes (4) provided by WCM, Inc.

Since CHARM-2 potential sensors detect the difference between essentially the top surface and wafer substrate, only charging phenomena in which the fingerprint induces this type of potential gradient will be detected. Electron shading type phenomena will not be detected. Gross charging phenomena such as plasma non-uniformity, non-uniform RF coupling, ESC glitches, etc. can possibly be detected. In addition to the potential sensors, the UV sensors are useful for characterizing down stream systems.

The following case studies are presented to demonstrate how CHARM-2 was used to diagnose charging issues seen in a high density etcher and assist in hardware optimization. There are numerous other examples, but for brevity, only 5 are presented in this abstract.

Case Study 1 – Process Issues: plasma non-uniformity issues

Although electron shading is the dominant plasma damage mechanism, a situation was encountered where a newly developed poly process showed yield loss at the wafer center. The cause of yield loss was low V_{BD} for the poly antenna WAT testers. The antenna ratio was not excessive, and the plasma density was quite low for the process, indicating that electron shading type damage was not the root cause. A CHARM-2 wafer was used to test the process to see if there were any problems unique to this process. A CHARM-2 signature mirroring the yield map was seen (figure 1). Areas of high charging on CHARM-2 were areas where there was no yield.

It was then determined that the top to bottom power ratio was too low – this resulted in the plasma being driven by the bottom RF which led to a very non-uniform center to edge plasma. Splits run on CHARM-2 showed that increasing top power by 2X reduced the charging signature (figure 2), and reducing the bias by ½ eliminated all charging (figure 3). A comparison of the current sensors showed available current of about 25 micro-amps/cm^2 for the damaging process and noise level current readings for the new TCP controlled process (figure 4). When this retuned process was tested on the customer product lot, the profiles met specifications, and the yield problem was eliminated.

Case Study 2 – Hardware Issue: Pin lifter touching back of wafer

For one customer there was a yield loss problem in the center of the wafer (again, low Q_{BD} problem). A CHARM-2 test was run with the same process on a lab tool and showed no charging. It was then found that the customer tool had its lifter pins improperly adjusted so that the pins were actually touching the backside of the wafer. The lab tool then had its pins adjusted to touch the backside of the wafer and a CHARM-2 test was run. A charging pattern was seen that mirrored the customer's yield loss pattern (figure 5).

Once the customer had the lifter pins properly adjusted, the yield levels returned to normal. It is not certain what the charging mechanism was, but it was speculated that either uneven RF coupling through the wafer (differences in the wafer-to-ESC gap) caused the charging, or the pins provided an RF path through the wafers to ground.

Case Study 3 – Hardware Issue: Monopolar electrostatic chuck charging

CHARM-2 was used to diagnose a charging problem stemming from electrostatic clamping. For monopolar electrostatic chucks (ESC) it was discovered that the sequencing of the plasma ignite and ESC on steps were crucial to avoiding charging damage (5). It was found that if the ESC was turned on before the plasma was ignited, a large positive CHARM-2 signature was seen (figure 6a), whereas no negative charging was seen. Further testing showed that this charging was due to the wafer potential rising to the chuck potential and causing a DC glow discharge. The DC glow discharge was also confirmed in two ways: 1. application of the bottom RF, while not enough to ignite a plasma, when the DC discharge occurred was able to sustain a visible discharge, as its application would sustain a visible discharge, and 2. onset of discharge caused the wafer to clamp, indicating a plasma was ignited. Since the wafer is at a large negative potential, the unipolar signature from CHARM-2 that is opposite in polarity to the chucking voltage also confirms this mechanism.

In the case where the plasma is ignited first, the wafer potential is held near the plasma potential, and the subsequent ESC chucking voltage will not induce charging damage. Subsequent CHARM-2 tests with this sequence showed no charging (figure 6b), and subsequent steps have been taken to ensure that etchers with monopolar chucks have the proper turn on sequence.

Case Study 4 – Hardware Development: Non-uniform RF through wafer

In some early CVD development work at Lam a high temperature ESC was being prototyped. As part of the standard procedure in the development work, the ESC was tested with a CHARM-2 wafer. An unexpected large CHARM-2 signature was seen. Later work showed that there was a large variation in the ESC dielectric, and this variation correlated to the charging map generated by CHARM-2 (figure 7). The non-uniform dielectric generated a non-uniform RF drop across the ESC dielectric, which resulted in non-uniform RF coupling through the wafer. Needless to say, this ESC was promptly decommissioned.

This type of non-uniform RF coupling through the wafer was seen in another situation where there was a large Si particle (100-200 µm diameter) on the ESC (figure 8a). Of course, the wafer did not chuck properly, but the non-uniform gap between the wafer and the ESC top surface generated a non-uniform RF drop across the wafer resulting in a large positive and negative gradient across the wafer. The particle caused one side of the wafer to lift and a corresponding top-bottom charging map was seen. Once the ESC was cleaned, the charging was eliminated.

Case Study 5 – Hardware Development: Down stream etcher and UV detection

This last case shows the utility of CHARM UV sensors in assisting hardware design. In prototyping work baffle design for a down stream etcher, it was important to block the ions and UV from the wafer. Although line of sight can be easily determined, unforeseen reflections that could allow UV to the wafer surface is more difficult to determine. CHARM-2 was used to ensure that baffle design did indeed block all ions and UV at the wafer level. Although the non-optimized baffle did not permit ions to reach the wafer (CHARM-2 map was clean), the baffle did allow UV through (Figure 9). With the final optimized baffle design, all the reflections were eliminated, and there was no UV response from CHARM-2.

Summary

Although electron shading is currently the dominant damage mechanism in high density etchers, other types of damage that are plasma uniformity or RF related can occur. The above case studies illustrate the utility of CHARM in detecting charge damage in these non-conventional cases. The utility of CHARM is also seen in its ability to assist with hardware development.

Acknowledgements

The authors thank BeMing Yen for his work on monopolar ESC damage and Steve Lassig for his CVD ESC data.

References

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2. V. Vahedi, et al, 2nd Int. Symp. P2ID, pg 41 (1997).
3. R. Patrick, et al, 2nd Int. Symp. P2ID, pg 59 (1997).
4. WCM technical notes, Analysis and Interpretation of CHARM®-2 data.
5. Lam internal report, BeMing Yen.

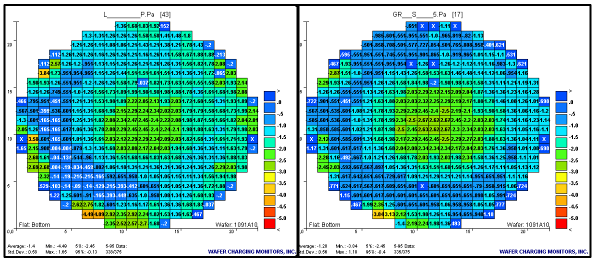

Figure 1. Potential sensors showing charging when running customer process. Unipolar (left) and guard ring sensors (right).

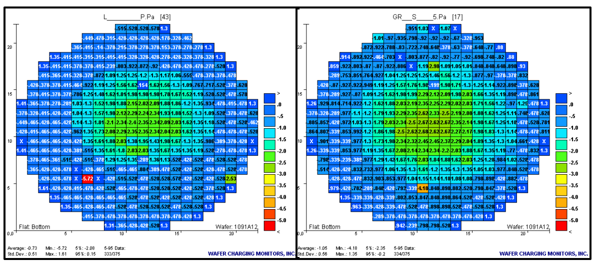

Figure 2. Increasing TCP power by 2X reduced but did not eliminate charging.

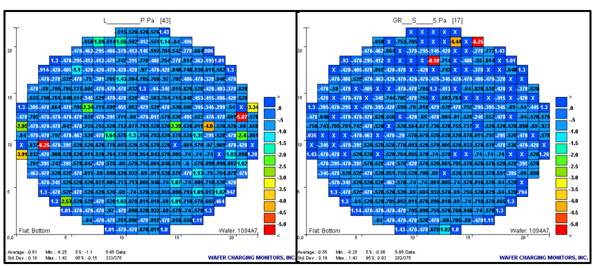

Figure 3. Increasing TCP power 2X and decreasing bias by half eliminated charging.

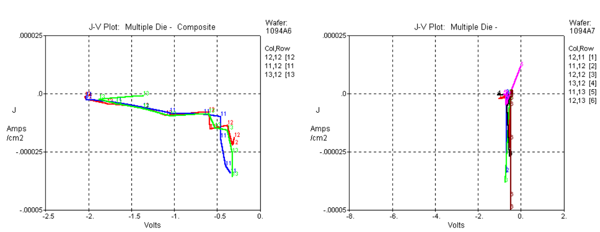

Figure 4. Current sensors comparing baseline (left) with charging free process (right).

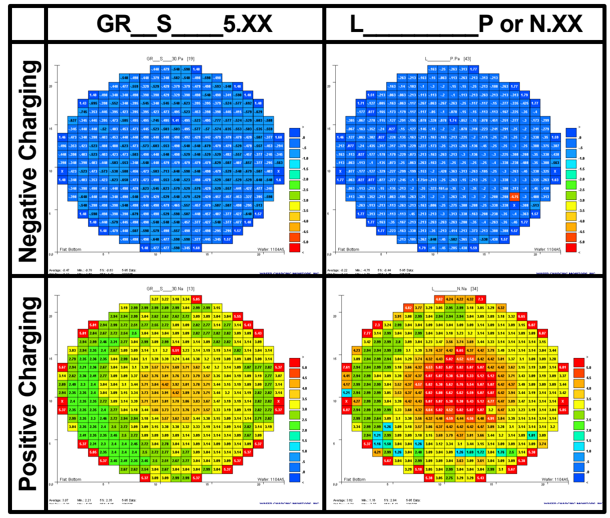

Figure 5. CHARM response with lifter pins touching bottom of wafer.

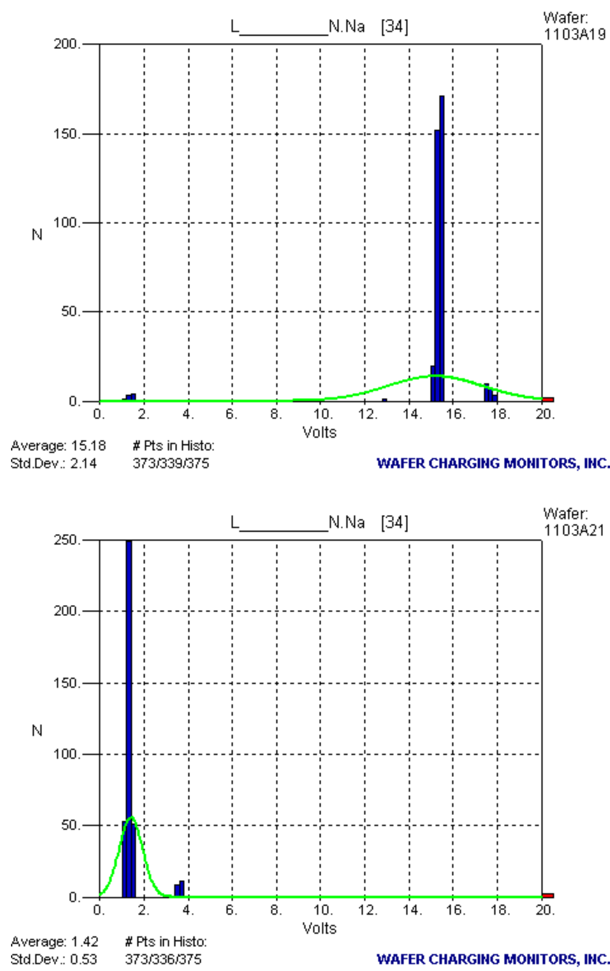

Figure 6. Saturated CHARM sensors from improper chucking sequence (top) and with proper sequence (bottom).

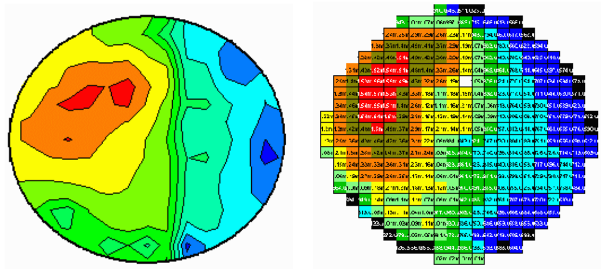

Figure 7. ESC dielectric thickness map (left) and corresponding CHARM map (right).

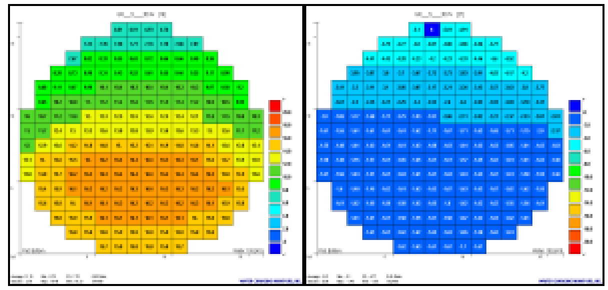

Figure 8b. CHARM signature due to particle (8a) under the wafer.

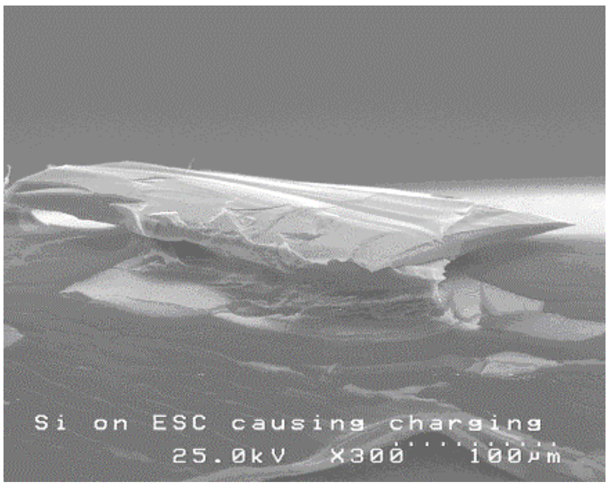

Figure 8a. SEM image of particle causing CHARM signature.

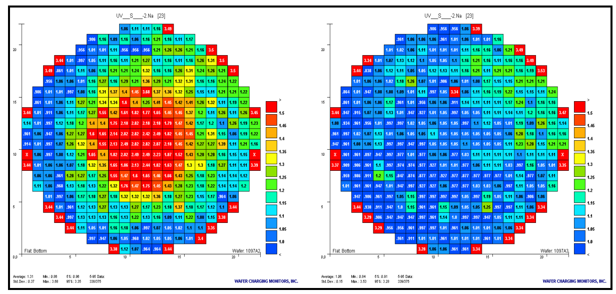

Figure 9. UV sensors, non-optimized baffle (left) versus optimized baffle(right)