
Hercules® – Tool for Technology Improvement and Fault Detection @ Micron's Etch Chambers

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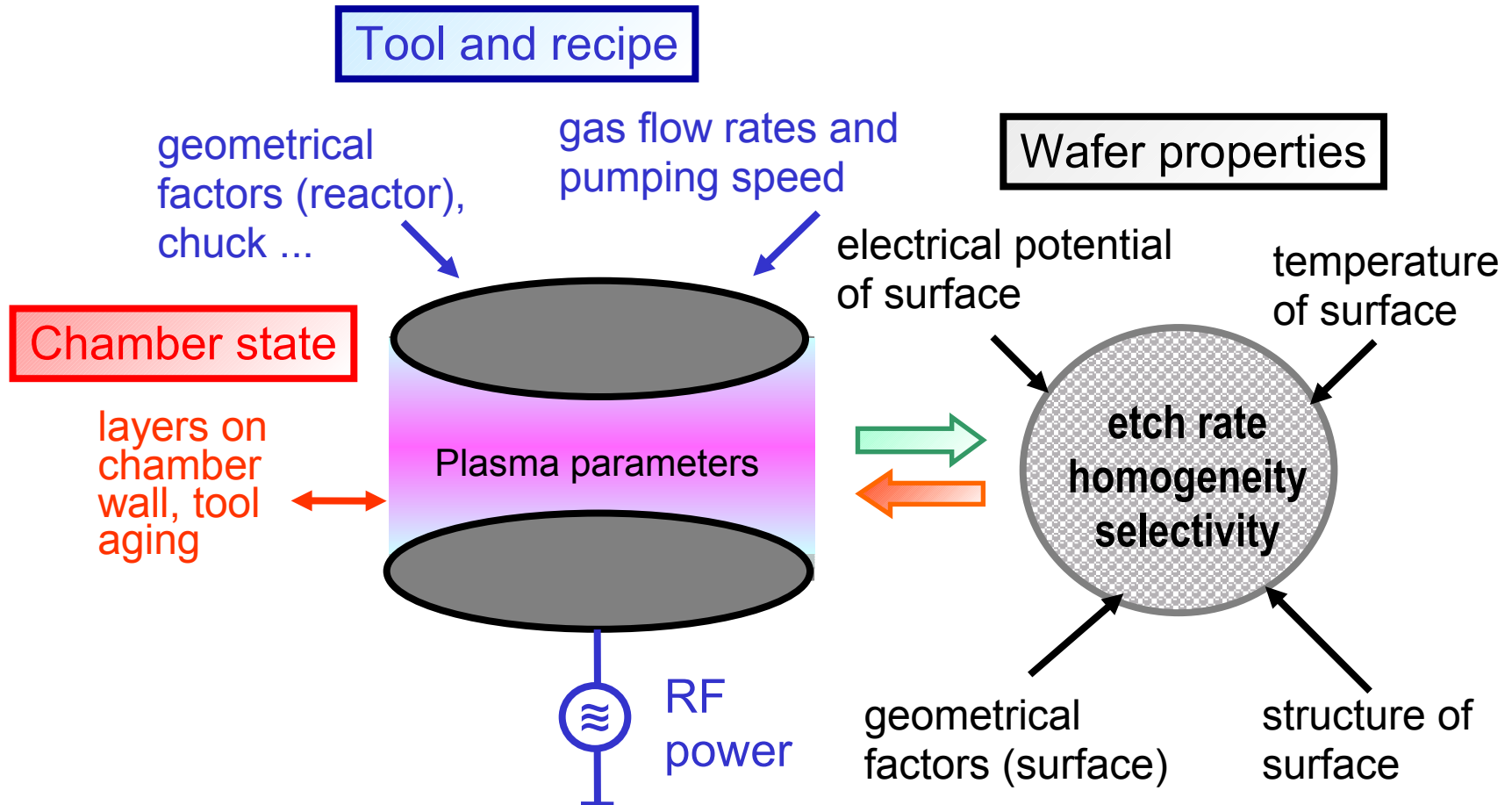
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Motivation

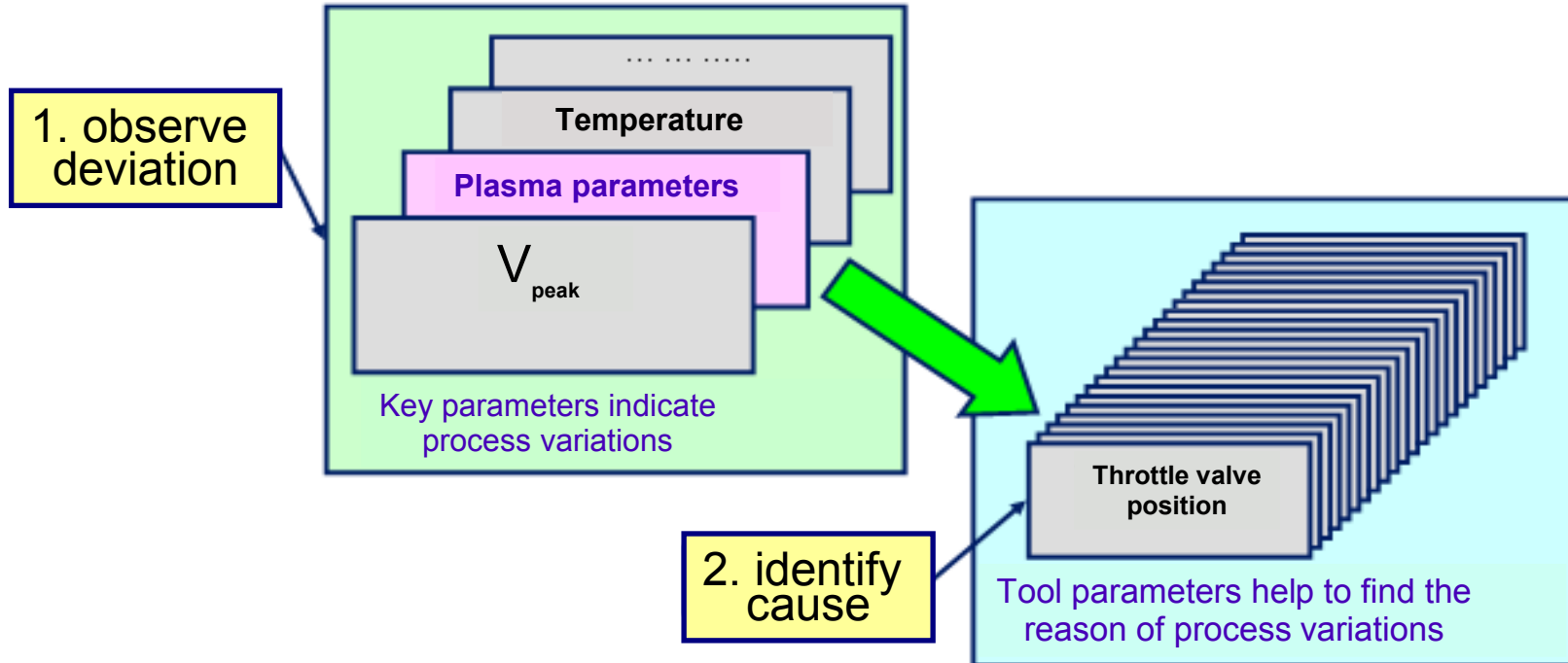
- The most significant process or tool parameters should be used for a more effective way of process control. The investigation was focused on:
 - ◆ Process stability within the lot and lot to lot.
 - ◆ The variation of different chemistries and a number of different process conditions.
 - ◆ application of the plasma monitoring system Hercules[®], based on Self Excited Electron Resonance Spectroscopy [SEERS] at a TCP[®] Etch and a Dual Frequency Oxide Etch Chamber.

The complexity of plasma parameter interaction



Use process key parameter for easy data handling

- Deviation from the mean of the process parameters in a trend chart indicates probable faults.
- Both plasma and tool parameters are necessary for fault detection and classification.

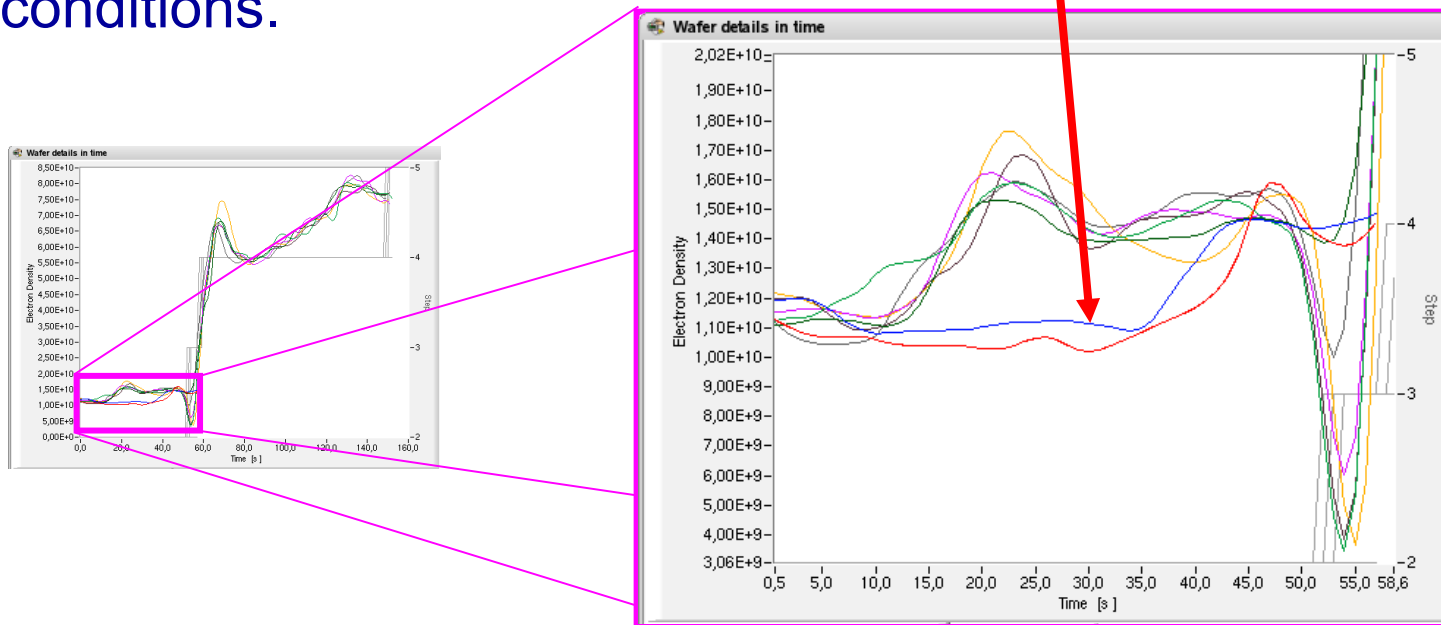


Investigations at a TCP[®] etch chamber

- Tool: TCP[®] with plug&play sensor interface
- Used parameters: Electron collision rate, plasma density
- Process: Carbon Dry Etch, Gate Stack Etch
- Multi-step recipe
- Main focus in this study:
 - ◆ Etch stability
 - ◆ Efficiency of Wafer-less Auto Clean (WAC[®]),
 - ◆ Check of Preventive Maintenance (PM) by plasma parameter (electron collision rate)
 - ◆ Tool Fault Detection and Classification (FDC)

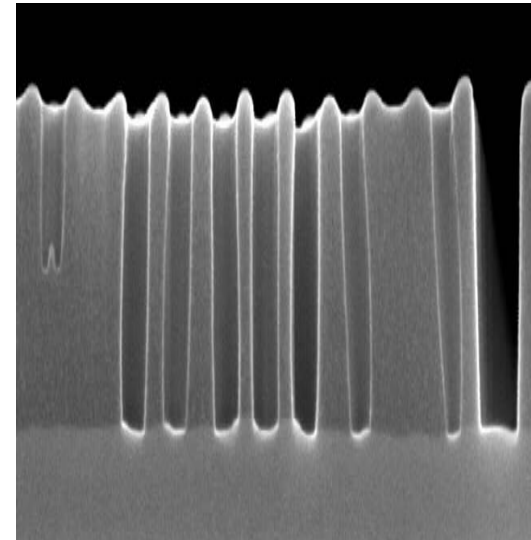
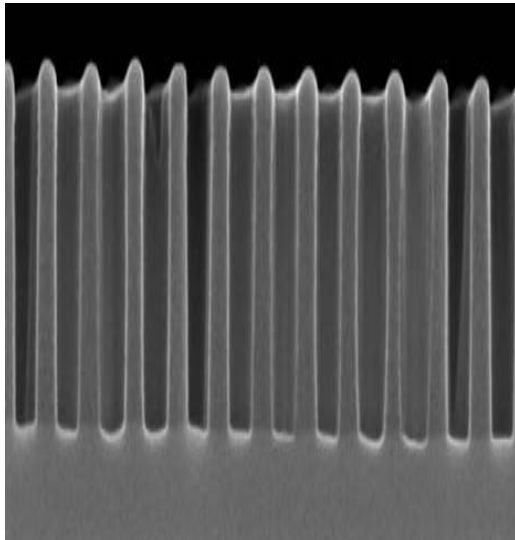
Plasma density used for FDC

- Time resolved data of regular and failed processed wafers show an increase of plasma density of about 40 % during the first step. Only the plasma density was sensitive enough for this indication.
- The density increase for the two affected wafers occurs much later than for the regular ones indicating different surface conditions.



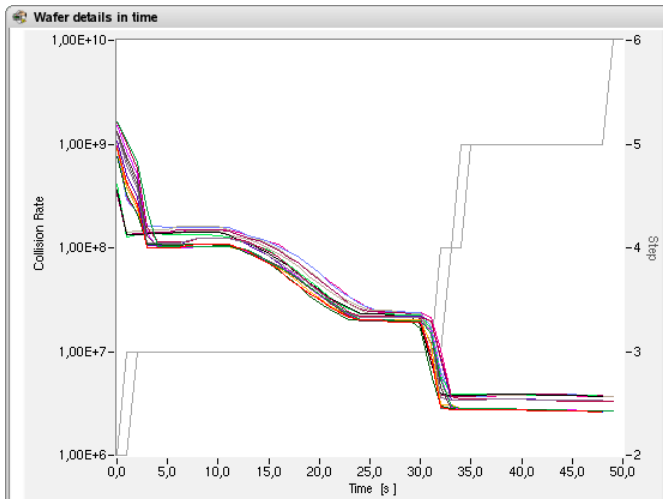
Reason and consequences of process faults

- The reason for this excursion was that these two wafers had missed the time window from resist application to exposure. The plasma density detected the problem before the optical endpoint detector did.
- The pictures below show normal and bad etch results.

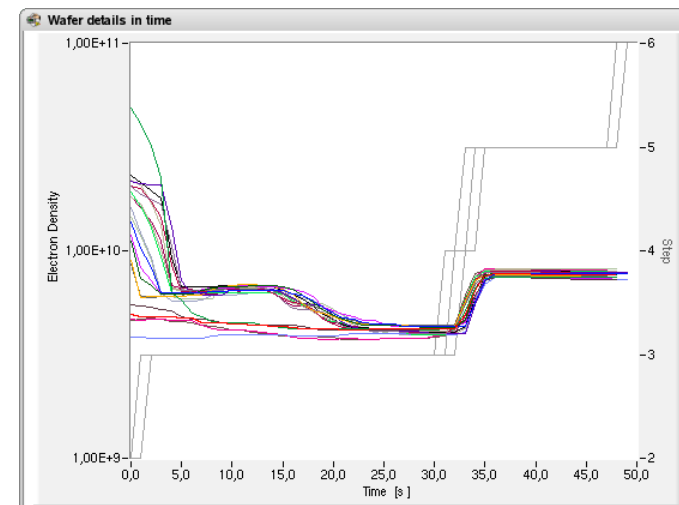


Potential of WAC process time saving

- The collision rate as well as the plasma density stabilize after 20 - 25 s of process step 3.



- The variation in the first 20 – 25 s is due to conditioning mechanisms.
- The first WAC[®] step has a potential time savings of 20 %.



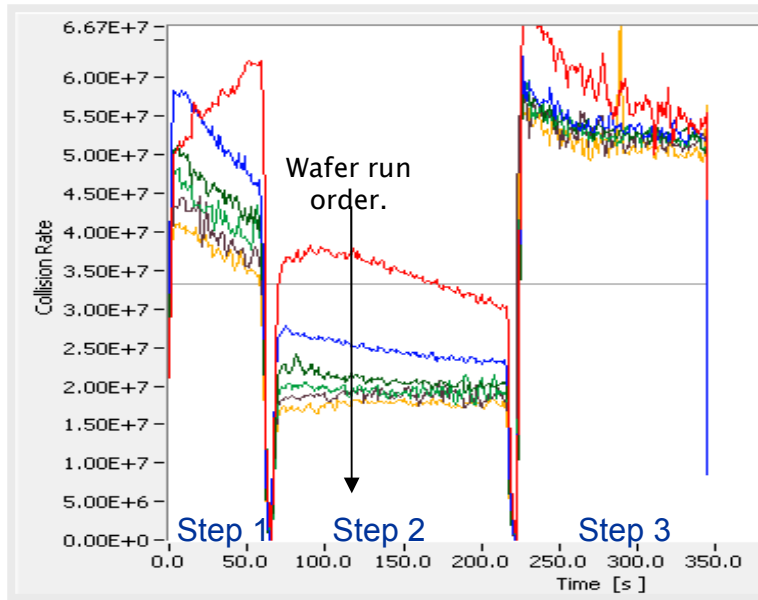
Summary

- Internal plasma parameters are very sensitive and show process/hardware changes that are not always visible by tool parameters, e.g. shift in electron density but no in-line parameter shifts.
- The electron density was able to identify two faulty wafers in a lot earlier than the endpoint detector did.
- Plasma parameters are useful for process optimization. An opportunity to shorten a WAC[®] process was identified based on a stabilizing collision rate, which indicates chemical processes are at a steady state.
- Hercules sensor is compatible with TCP[®] etch chamber, no impact to process was seen.
- The plug & play sensor interface of the Lam Domino platform allows very comfortable and efficient sensor data utilization.

Process improvement at a dual frequency etch chamber

- Tool: Oxide Etcher
- Observed parameters: Electron collision rate, plasma density
- Process: Contact etching
- Multi-step recipe
- Main focus in this study:
 - ◆ First wafer effects
 - ◆ Optimization of seasoning procedures
 - ◆ Impact of incorrect maintenance measure (simulated) to plasma conditions.

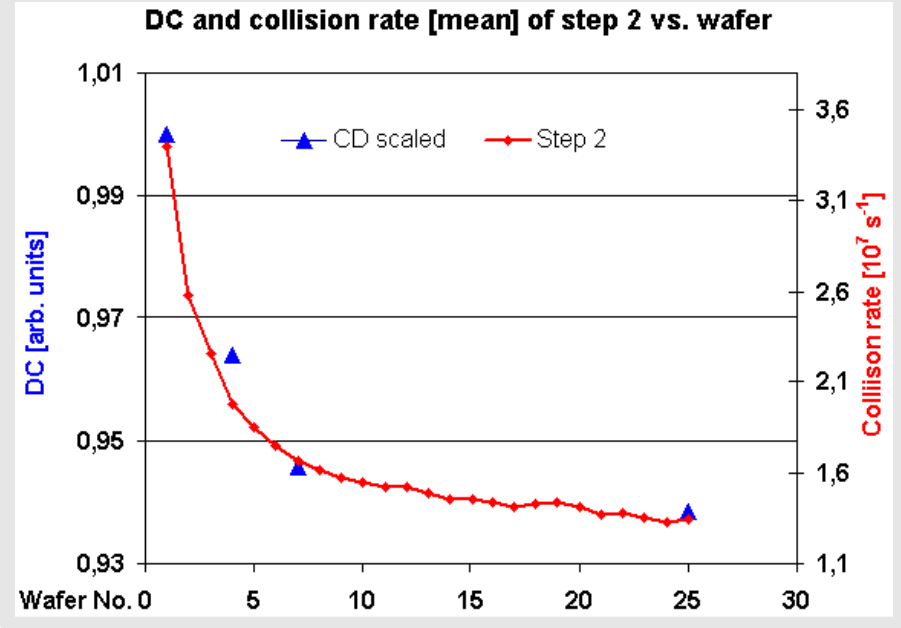
First wafer effect of collision rate and CD



Most of the collision rate drifting occurs in the first and second steps with a strong change of shape for the etch step 1 between the first and second wafers.

CD correlates with collision rate.

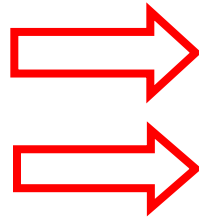
The temperature of the electrode has not stabilized after seasoning → an improved warm-up is required.



Control of crucial plasma parameters

- The important process parameter is the density of neutrals n_n which depends on pressure p and gas (neutrals) temperature T_n .

$$n_n = \frac{p}{k_B T_n}$$



Power dissipation for chemistry by electrons (collision rate).

Energy and angle distribution of ions determines etch profile.

Basic equation of the ideal gas:

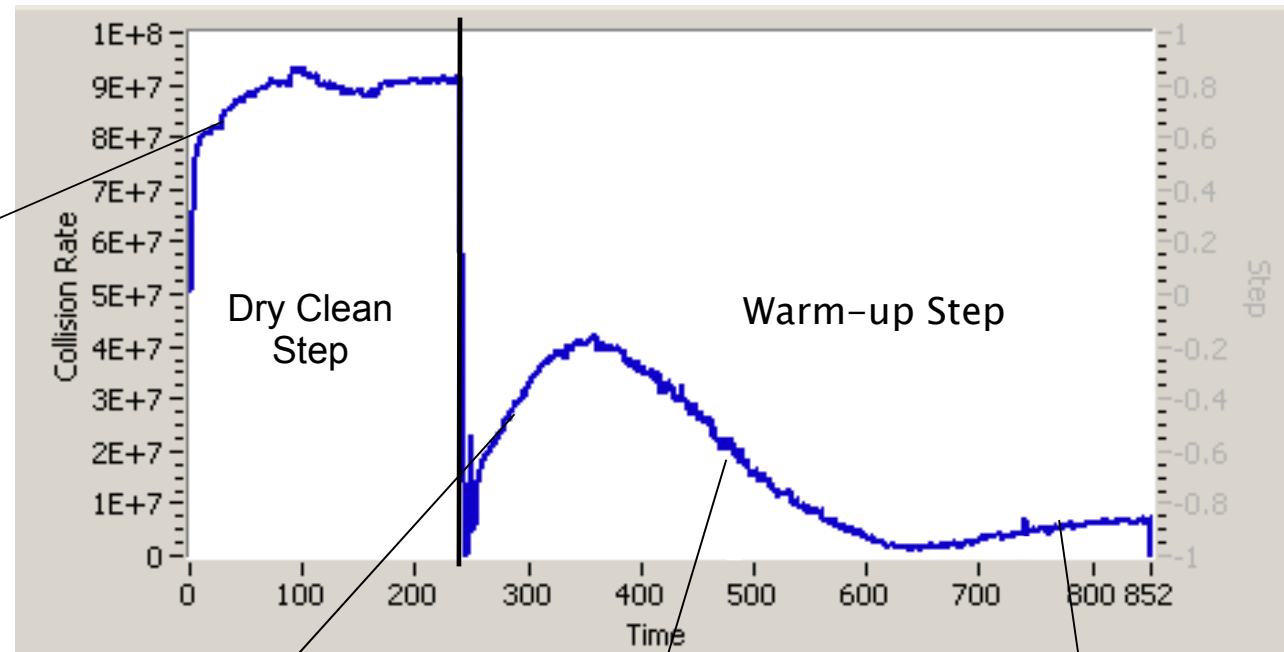
n_n : Density of the neutrals	→	crucial process parameter
p : Pressure	→	adjustable tool parameter
T_n : Gas (neutrals) temperature	→	hardware parameter (chamber temperature)
k_B → Boltzmann constant		

- First wafer effects are mostly due to chamber warm-up until reaching a stable temperature.
- Constant pressure and increasing gas temperature in the chamber result in less gas for the process – also in case of mass flow control → the collision rate decreases !

Warm-up modification to minimize first wafer effect

Collision rate vs. time for modified Warm-up process

Chemical clean to remove polymer deposition in the chamber.

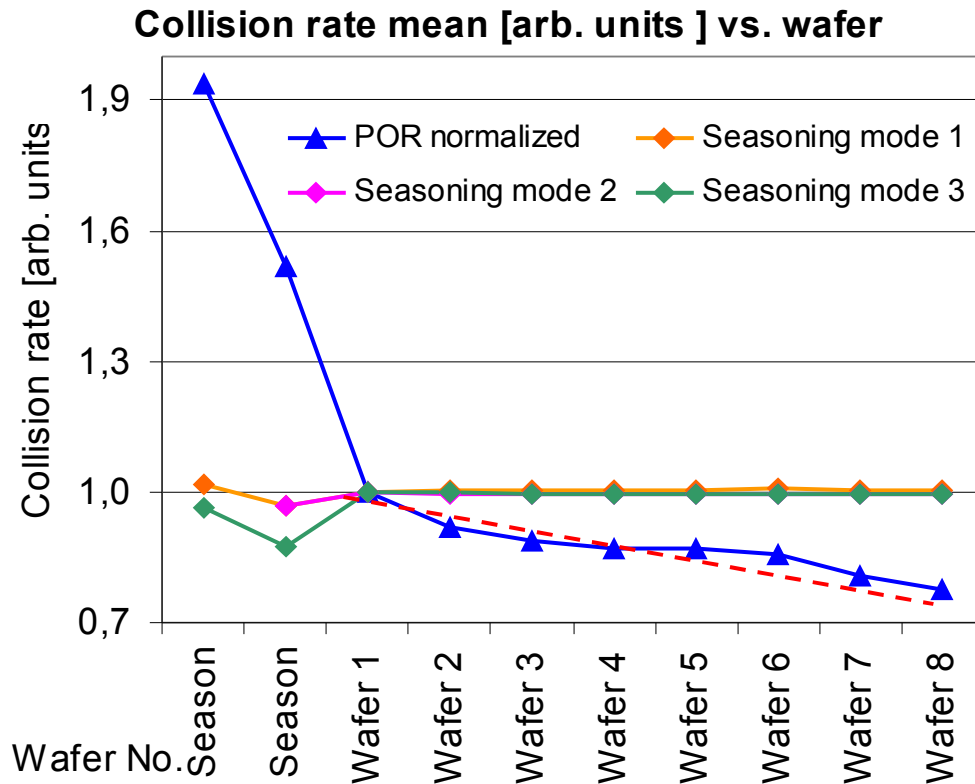


The increase of collision rate at the start of warm-up step is possibly a further seasoning of the chamber.

Heating of CEL indicated by decreased collision rate.

Process Stabilizes

Stabilize the etch process by seasoning modification



POR (Process Of Record) includes 5 dummy wafers for ≈ 29 min not including transfer time.

→ Drift on the first 3 wafers (not shown here).

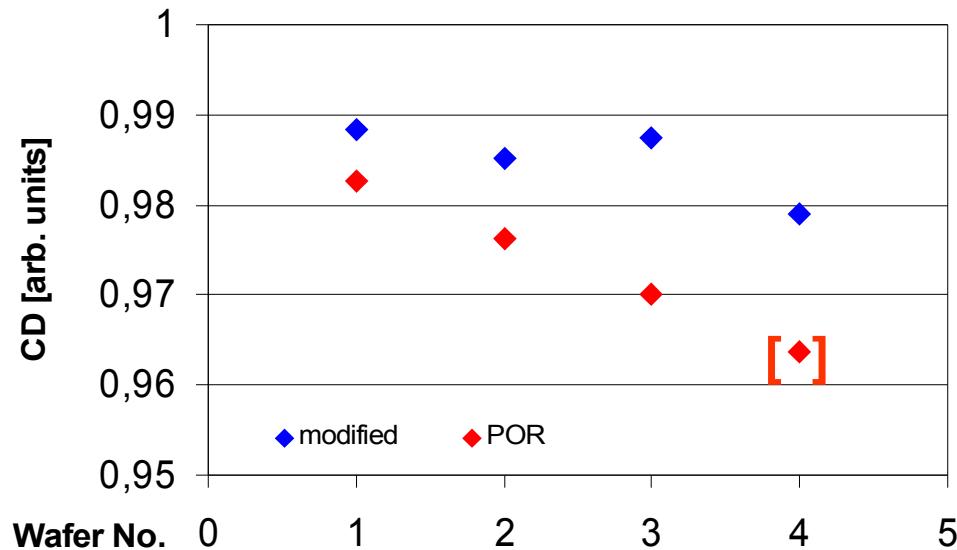
→ Trend of decreasing collision rate through the rest of the boat (dashed red line).

Seasoning modification (mode 1-3)

→ Collision rate is fairly constant.

→ 14 min (50% less time) (including the 4:00 dry clean)

CD of Structure Wafers for POR and modified seasoning



The amount of variation is reduced by $\approx 50\%$.

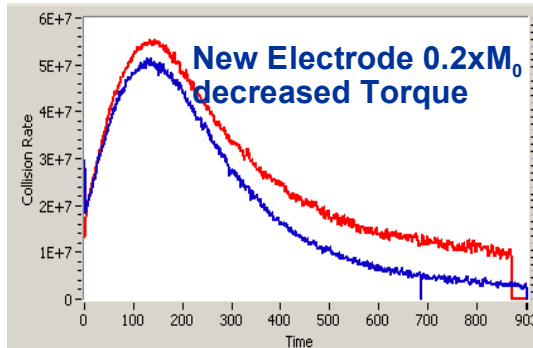
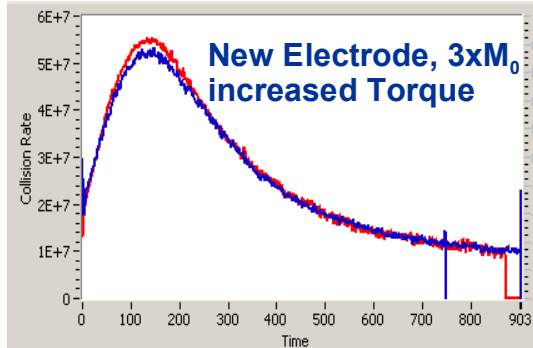
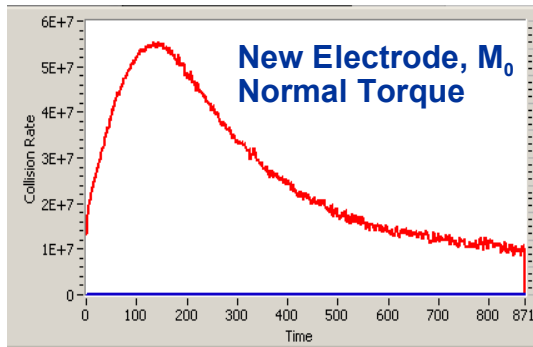
■ Modified seasoning

- ◆ across 4 wafers \rightarrow CD variation is 0.009.

■ POR

- ◆ across 3 wafers \rightarrow CD variation is 0.012
- ◆ would expect CD variation \rightarrow 0.018 if a fourth wafer [] was run.

Maintenance fault indicated by collision rate



- The standard torque for the electrode screws according supplier spec $\rightarrow M_0$
 - ◆ The red line is the time resolved curve for a warm-up process and the reference for the diagrams below.
- Increased torque $\rightarrow 3 \times M_0$
 - ◆ Both curves are identical, hence the heat removal keeps constant.
- Decreased torque $\rightarrow 0.2 \times M_0$
 - ◆ Lower collision rate due to higher Electrode temperature through bad heat removal and hence increased gas temperature.

Discussion

- Based on collected data it appears that the CD Drift across the first few wafers is due to a heating up affect of the upper electrode. The tool manufacturer verified this by their own data, showing the electrode to heat up way beyond the upper electrode set point.
- Running an extended high power warm-up etch shows to stabilize the collision rates from wafer to wafer.
- Running the extended high power warm-up etch to season the chamber reduces the amount of seasoning time by ~50% while also reducing the amount of CD variation across the first 4 wafers by ~50%.
- It is also possible that this may be able to be used as a test to determine if the upper electrode is reassembled properly (torqued correctly) after a chamber clean.

Summary

- Key parameters must be more sensitive than the process itself. They are indicators of deviation, drift, and process faults. Plasma parameters are useful control parameters. Their sensitivity, at least for the process under consideration, are much higher than the product parameters.
- Plasma parameters show how each step affects the subsequent step as the chamber condition of each step extends into the next one. As CDs get smaller and smaller so do the process windows and one needs to pay attention to these affects as they may be detrimental to the processes outcome.
- **Benefits**
 - ◆ Increased efficiency of WAC[®], higher uptime and availability for production
 - ◆ Real-time FDC
 - ◆ Reduces the amount of seasoning time by $\approx 50\%$
 - ◆ Reduced CD variation across the first 4 wafers by $\approx 50\%$