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In-Situ Real-Time Monitoring of a Via Etching Process

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Introduction:

Advanced Process Control / Advanced Equipment Control is explored for an industrial TEL Unity IEM via etcher with SEERS (Self Excited Electron Resonance Spectroscopy) using a Hercules sensor supplied by Advanced Semiconductor Instruments (ASI). SEERS extracts the electron collision rate and the electron density from the time-dependence of the electron current from the discharge. The following items are subject of the study:

- The sensitivity to process inputs, to equipment parts and to process mix on the chamber is demonstrated.
- A pronounced first wafer effect visible in electron density and collision rate was observed and could be explained by chamber temperature control.
- Fault Detection is studied using the data provided by the equipment.

Process Parameter Sensitivity

To check the sensitivity of Hercules to process inputs, a design of experiments (DOE) was performed.

- The DOE was done after wet clean and conditioning with 25 resist wafers.
- First run: resist wafers, second run: product-like wafers.

Parameter	Variation 1	Variation 2
Top Power	-18 %	-9 %
Bottom Power	-25 %	-12.5 %
Pressure	-17 %	+17 %
C_4F_8 Flow	-10 %	+10 %
O_2 Flow	-15 %	+15 %
Gap	-5 %	+ 5 %

Summary

Hercules is sensitive to the investigated process inputs. In particular, the collision rate depends on the oxygen and C_4F_8 flow, which are critical to the via etching process (see next slides for examples).

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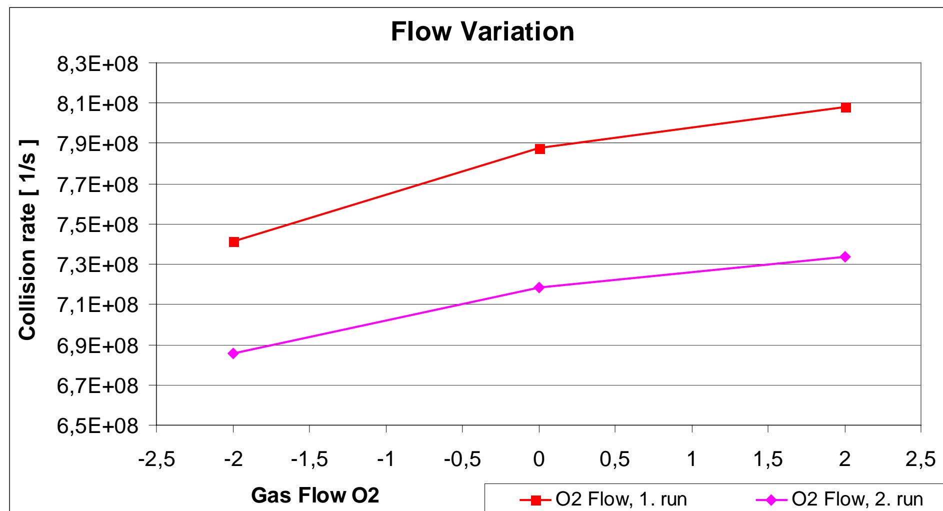
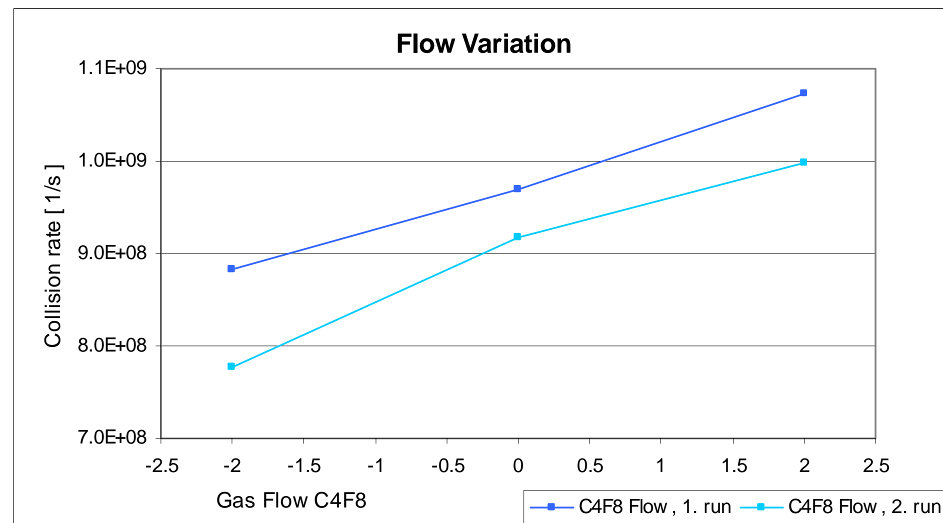
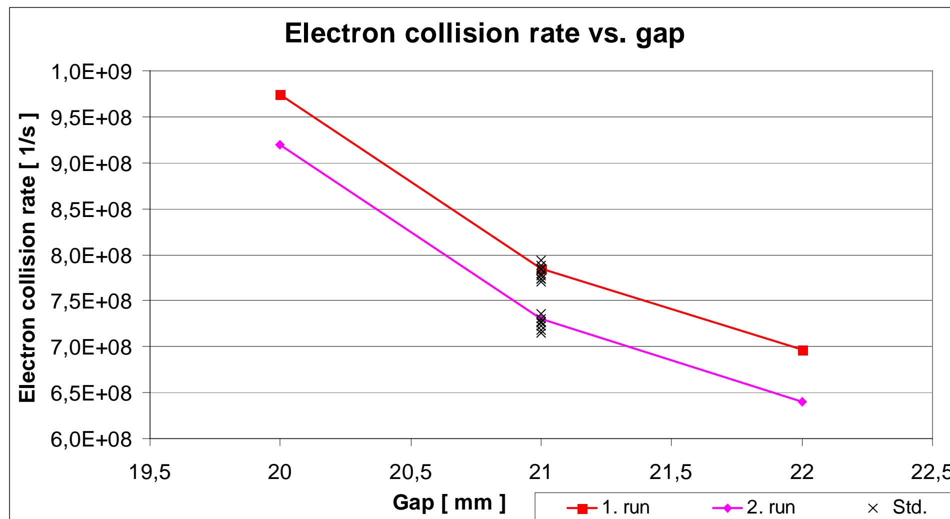


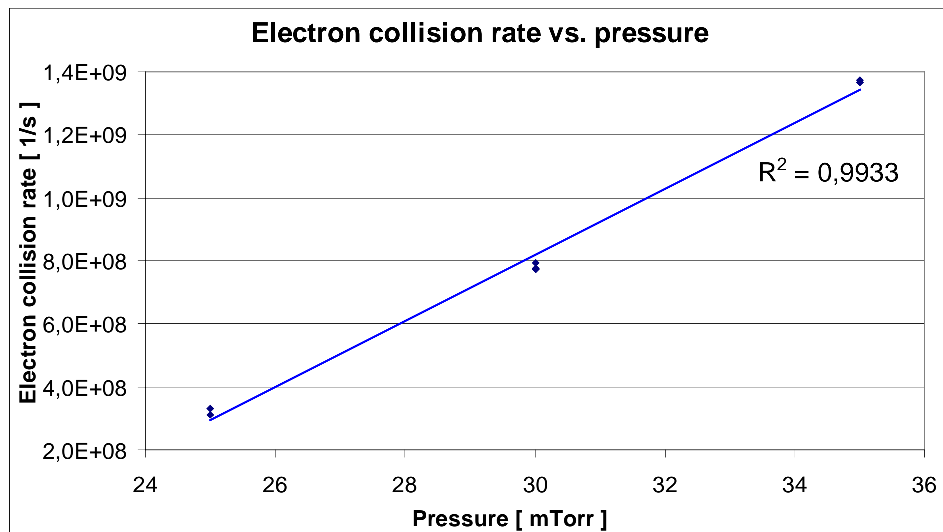


The diagrams on the left show the impact of C_4F_8 and O_2 flow. Their flows determine the C:F in the discharge which is well known to be one key parameter to control selectivity and etch stop behaviour in via etching. A higher content of C leads to enhanced polymerization increasing selectivity at a higher risk of etch stop.

Sensitivity to Process Inputs (3)

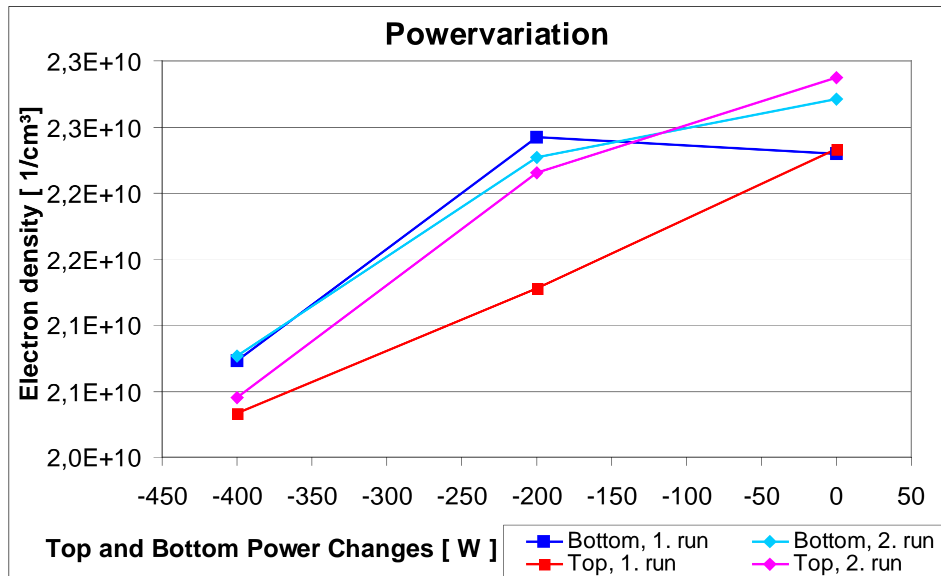


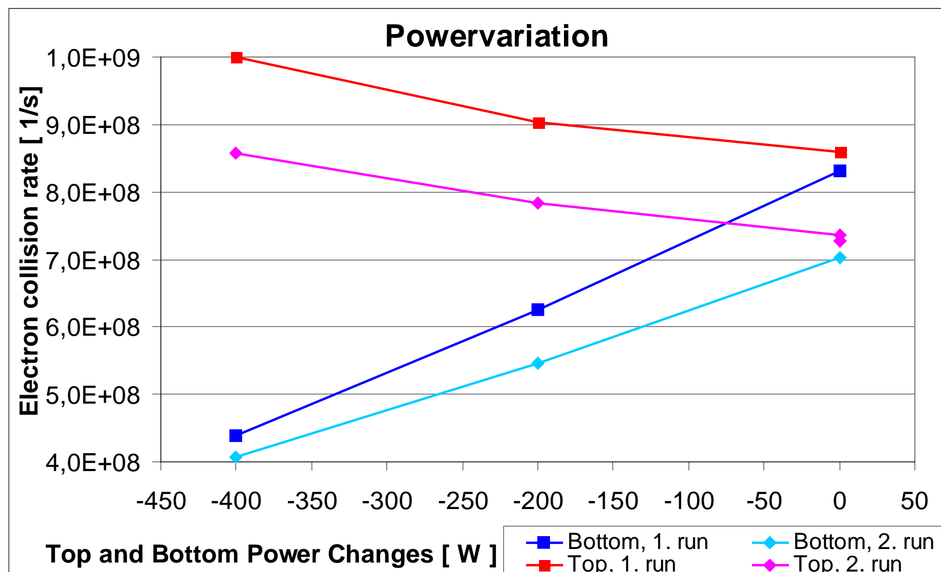
Electrode gap 21mm was varied +/- 1mm, that means +/- 5 %. The change of electron collision rate of about 18 % show the sensitivity to the plasma parameters.



The pressure of standard recipe was varied +/- 5 mTorr. The electron collision rate shows a nearly linear dependence on the pressure in the investigated parameter range.

Sensitivity to Process Inputs (4)





The electron density is reasonable and involves a systematic deviation, since the RF peak voltage is estimated internally.

Effect of power variation is more pronounced in the electron collision rate.

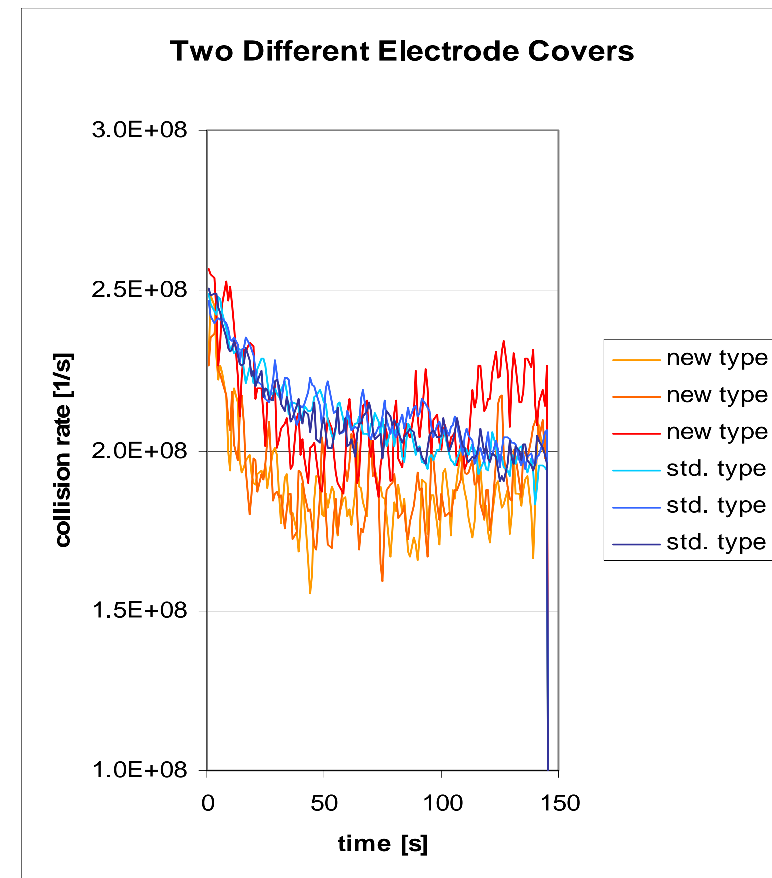
The difference between run 1/2 is not related to the kind of wafers (resist vs. product like), but to the different chamber conditions directly after a wet clean when the DOE was performed.

Sensitivity to Equipment Parts and Process Mix (1)

Hardware Sensitivity

A new lower electrode cover is evaluated.

- The collision rate is less stable for the new type, mean is not changed.
- The wafers were run after wet clean and conditioning with about 50 resist wafers.



Summary

Based on this observation the new part was not released for production, even if no clear impact to the etch process was observed. Further analysis will be done.

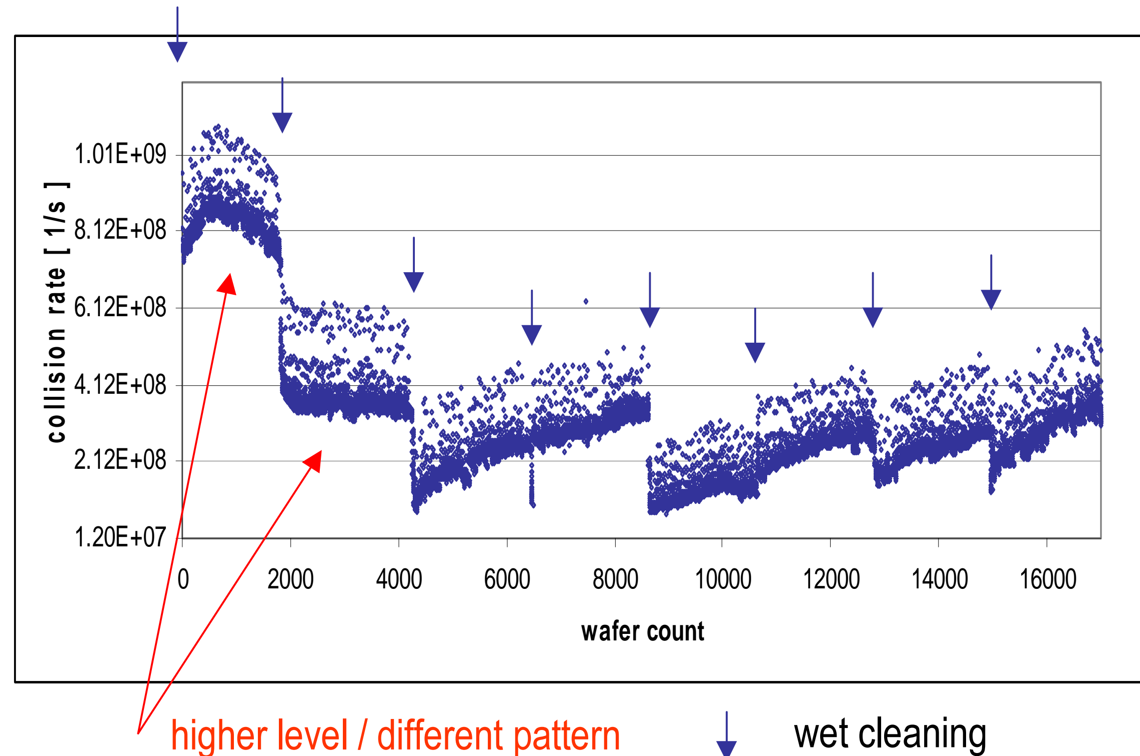
Sensitivity to Equipment Parts and Process Mix (2)

Process Mix Sensitivity

Before the sensor was installed, the chamber was used for a different gas chemistry ($Ar/C_5F_8/O_2$ instead of $Ar/C_4F_8/O_2$).

It took two wet cleaning cycles or about 4000 wafers completely „forget“ the former chemistry.

Steps after wet clean are probably related to changed consumables. Needs further analysis.



higher level / different pattern ↓ wet cleaning

Summary

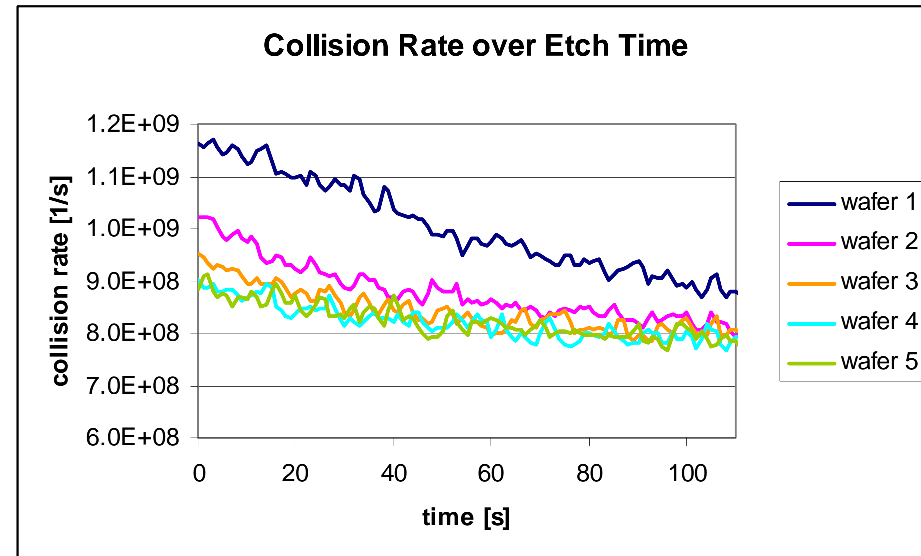
Chamber surface seems to have a significant influence to plasma parameters. This becomes more and more important for process control.

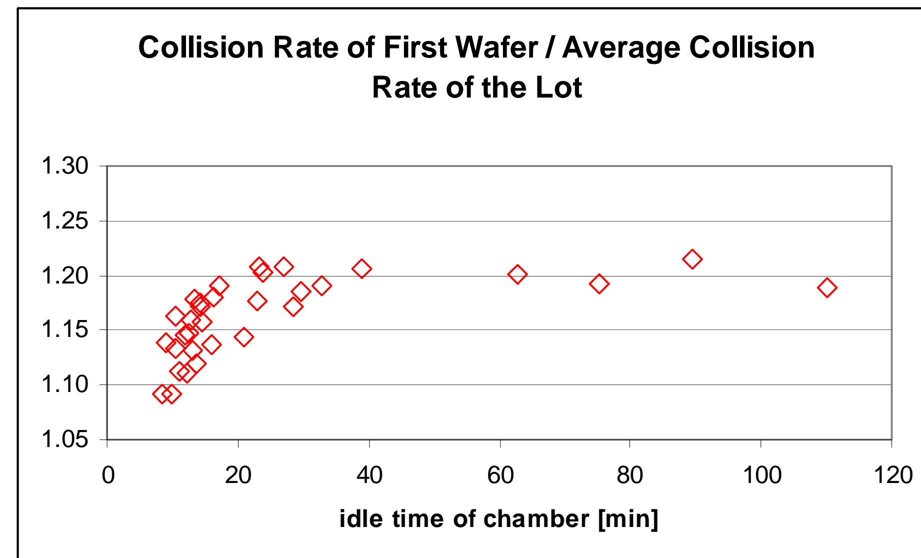
First Wafer Effect (Observation)

The average collision rate of the first wafer in a run is usually higher and there is also a decreasing tendency during the etching of one wafer.

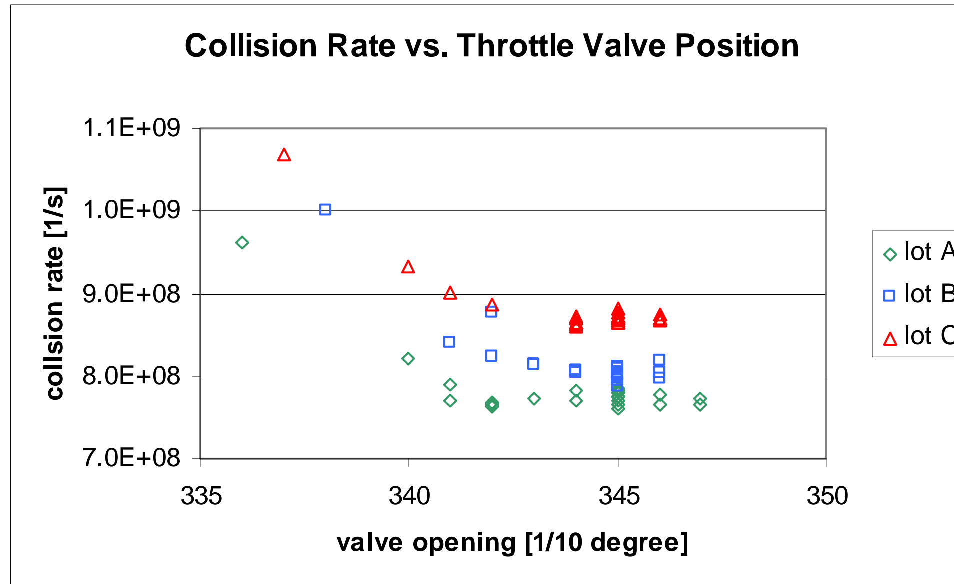
Detailed data analysis revealed, that the first wafer effect depends on the following parameters:

* Idle time of the chamber before starting the lot. The diagram shows that the effect disappears when the lots are started continously.

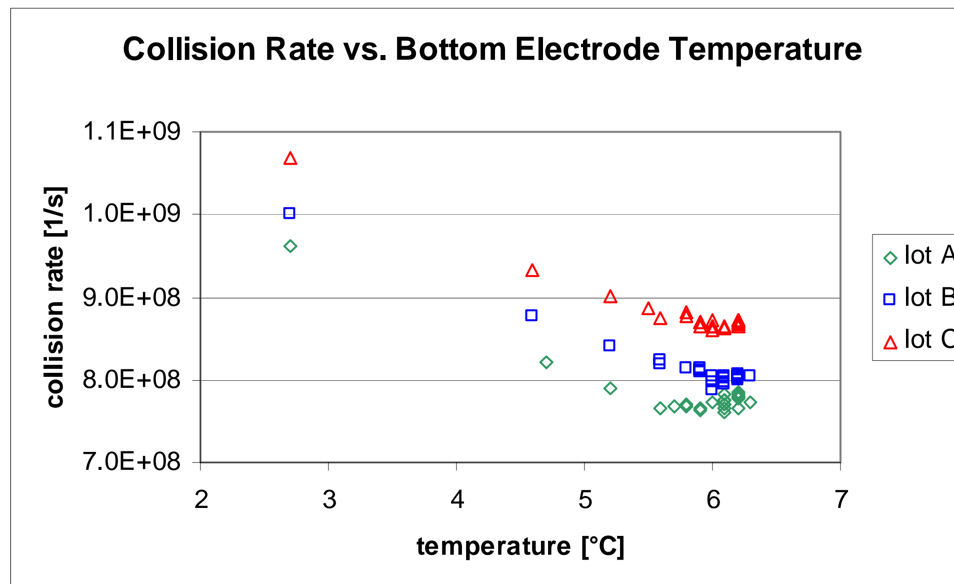




First Wafer Effect (2)



* Throttle valve position (automatic pressure control), adjusted during processing to keep the chamber pressure stable.



* Bottom electrode temperature (wafer is chucked on this elec-trode) the temperture is control-led by an external cooling circuit.

Summary and Interpretation

The electron collision rate is mainly depended on the electron-neutral collision rate. Under the assumption of an ideal gas the neutral density n is proportional to p/T (p pressure, T absolute temperature).

A higher electrode temperature leads also to an increased gas temperature and results (at a constant pressure) in a lower neutral density n. Therefore the decreasing collision rate at higher temperature is reasonable. This is also consistent with the higher throttle valve opening and the idle time dependency (longer idle time means lower temperature for the first wafer).

Conclusion

The neutral flow has an important impact to etching characteristics and therefore this effect should be minimized. It could be reduced by an improved temperature control of the equipment or the usage of warm up wafers.

Study of Equipment Parameters

Evaluation of Fault Detection

Evaluation of Fault Detection

- For the present the evaluation is limited to equipment parameters since there are only a few SEERS data available so far.

- The temporal mean of each parameter is used.

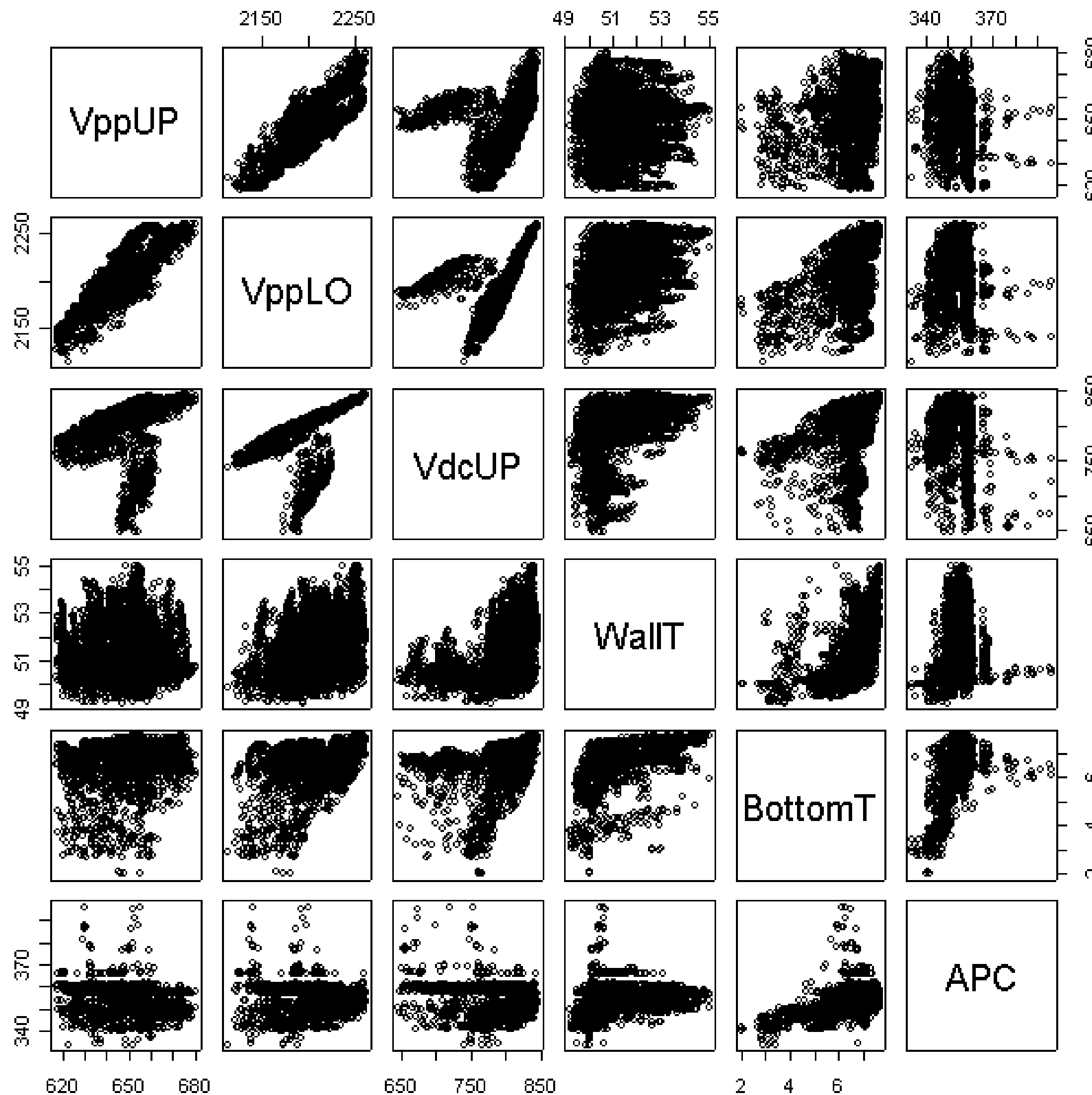
- Parameters that (1) vary from wafer to wafer and (2) correlate to each other are treated multivariately. These are: Peak-to-peak voltage at upper and lower electrode (Vpp), self-bias at upper electrode (Vdc), wall and bottom temperature and throttle valve position (APC).

- A Principal Component Analysis is done, yet the rank of the data matrix is not reduced (see next page).

- A Hotellings T^2 control chart is set up for these parameters.

- All other parameters are monitored by univariate charts.

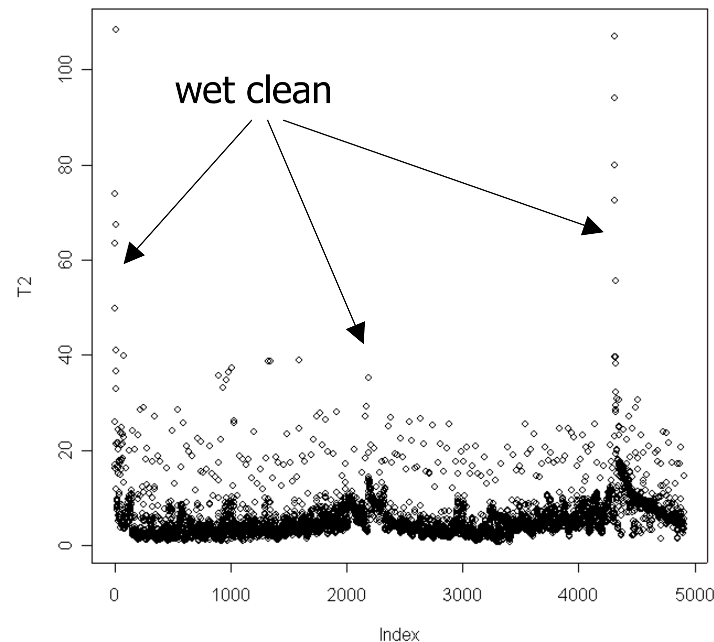
Fault Detection (2)

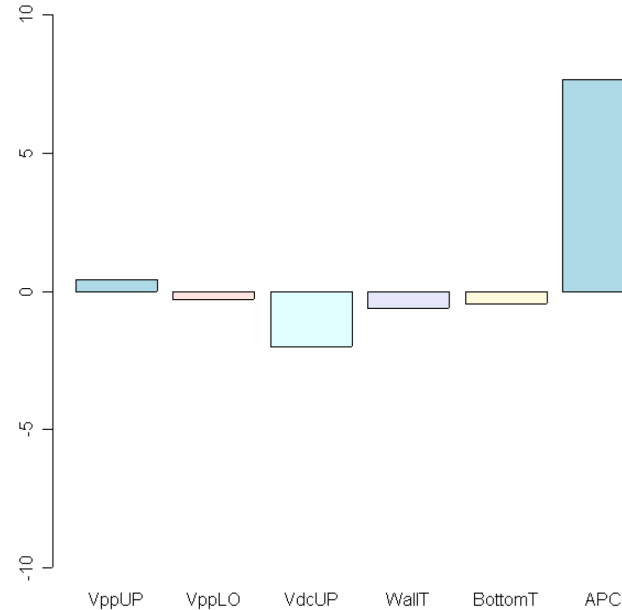


- Vpp at upper and lower electrode are most strongly correlated
- In the Vpp/Vdc plots there are two modes visible which might be attributed to the exchange consumables
- Several parameters show a first wafer effect resulting in some correlation

All in all the parameters are not highly correlated.

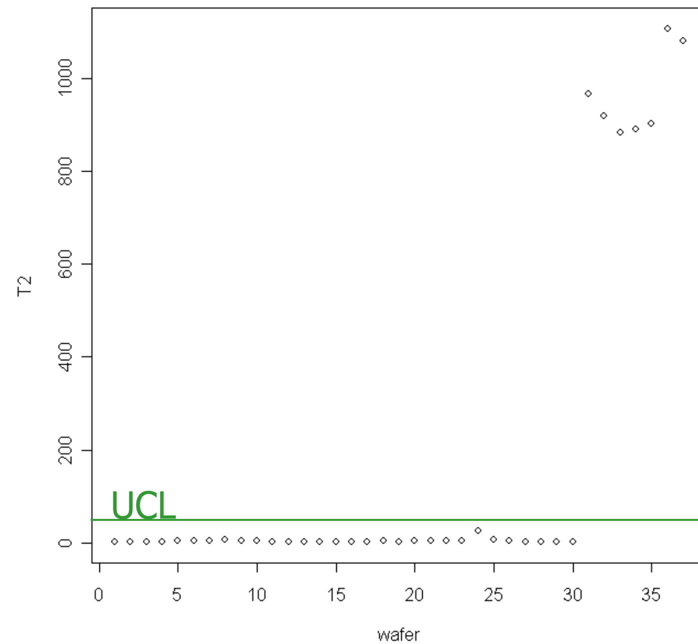
Fault: Increased T^2 after wet cleaning





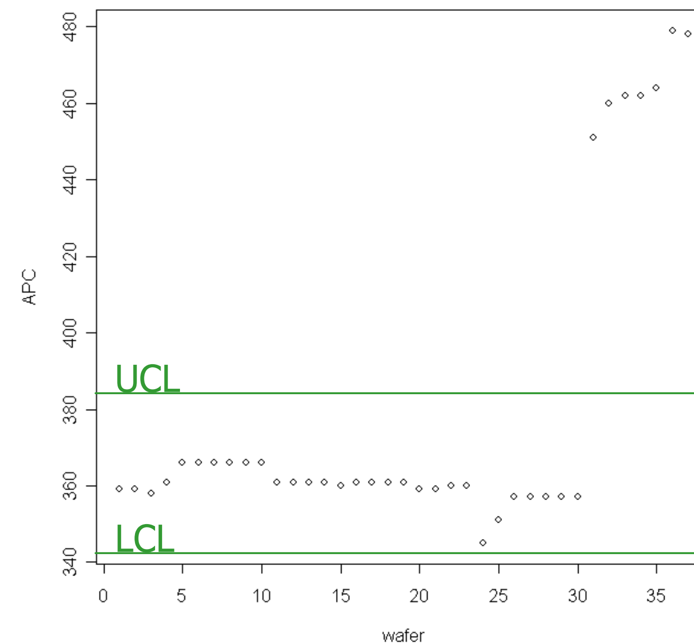
- After wet clean sometimes an increased T^2 value is observed
- The contribution plot on the left side points to abnormal APC (Vdc)
- The conditioning after wet clean has to be improved

Fault: Leak in the process chamber



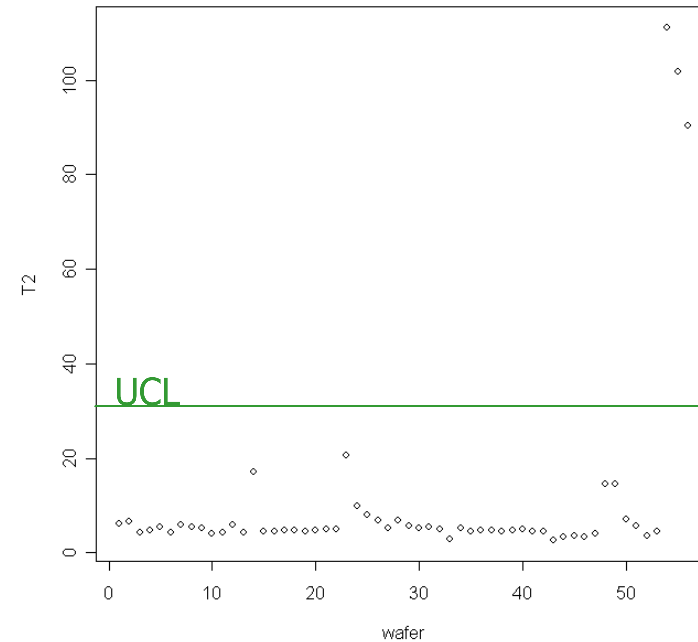
Damage occurred to the EPD window resulting in a leak in the process chamber. Left graph: T^2 chart.

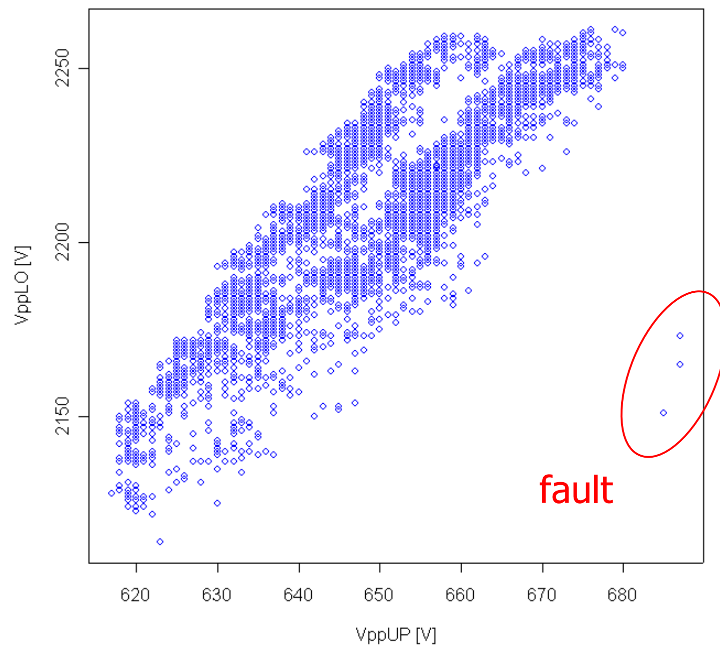
The leak could of course also be detected by a univariate chart for the throttle valve position (right graph).



Fault: Breakage of the upper electrode

Before the upper electrode broke, three wafers showed an increased T^2 value (see right graph).





For the three wafers before the breakage the Vpp at the upper and lower electrode are not correlated in the usual way. This fault could hardly be detected by univariate charts.

Conclusion

It could be demonstrated that SEERS is very sensitive to process-para-meters. SEERS can be used as a powerful methode to detect tool- or process-failures.

Using Principal Component Analysis and a T^2 control chart, we evaluated Fault Detection for the via-etch chamber.

SEERS can be used for qualification of consumables and the optimization of wet cleans.

Outlook

A correlation of particle-levels and discharge-parameters seems to be possible.