

Use of data mining techniques for model based data analysis of plasma parameters and electrical data in high volume DRAM production

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Outline

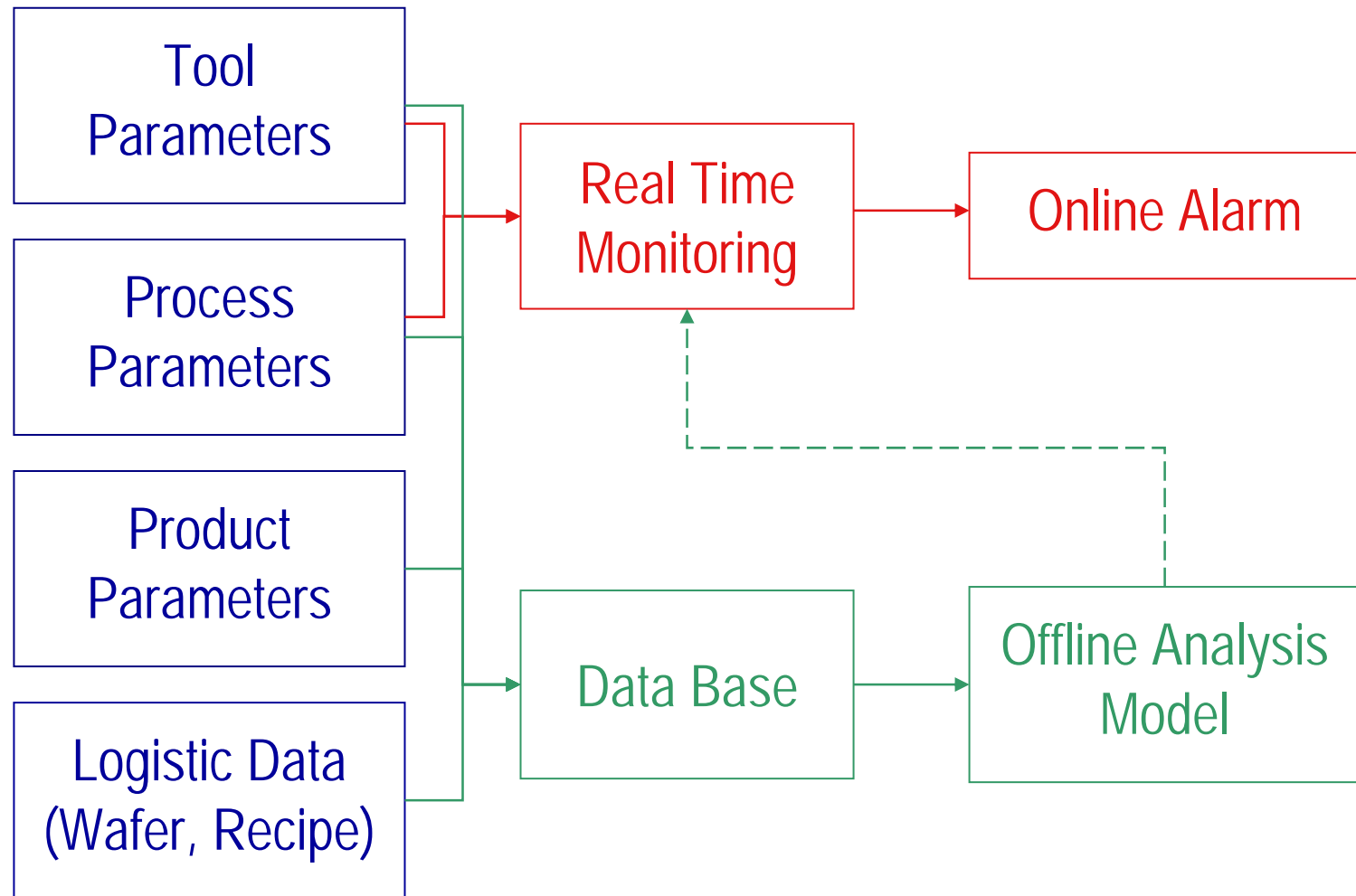
- APC in high volume production
- Data reduction by
 - Measurement techniques based on physical models
 - Application of statistical key numbers
 - Use of complex process parameters
 - Model based data analysis – Data Mining
- Application of model based data analysis on gate stack etch at LAM TCP
 - Experimental data
 - Historical data
- Summary and outlook



APC in high volume DRAM production

- In comparison to the sophisticated analysis methodology on product, the level of unit process mastering offers much less information. The ratio of electrical data to in-line data may be approximately 30 : 1.
- Tool alarms and test methods are still not sensitive enough for early failure detection. Process problems are detected too late by in-line measurements.
- There is a gap between the high sophisticated yield analysis methodology on product and the comparatively low level of unit process mastering.
- The application of Advanced Process Control using in-situ measurement techniques and high sophisticated data analysis offers a chance to overcome this gap.

APC consists of offline analysis and real time process control including alarms



Data reduction – an essential need for APC in high volume production

- Data reduction is an essential need for offline analysis and real time process monitoring, because the measurements of process and tool parameters in high volume production create very large amounts of data.

We distinguish between several methods of data reduction.

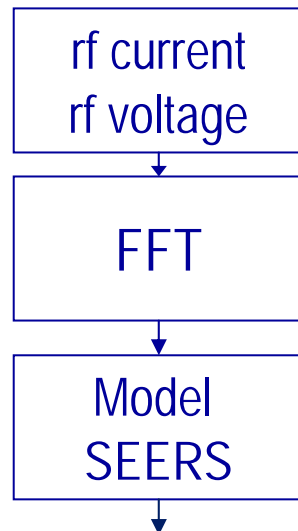
- Data reduction by
 - Measurement techniques based on physical models
 - Calculation of statistical key numbers
 - Use of complex process parameters
 - Model based data analysis

Data reduction by measurement techniques based on physical models

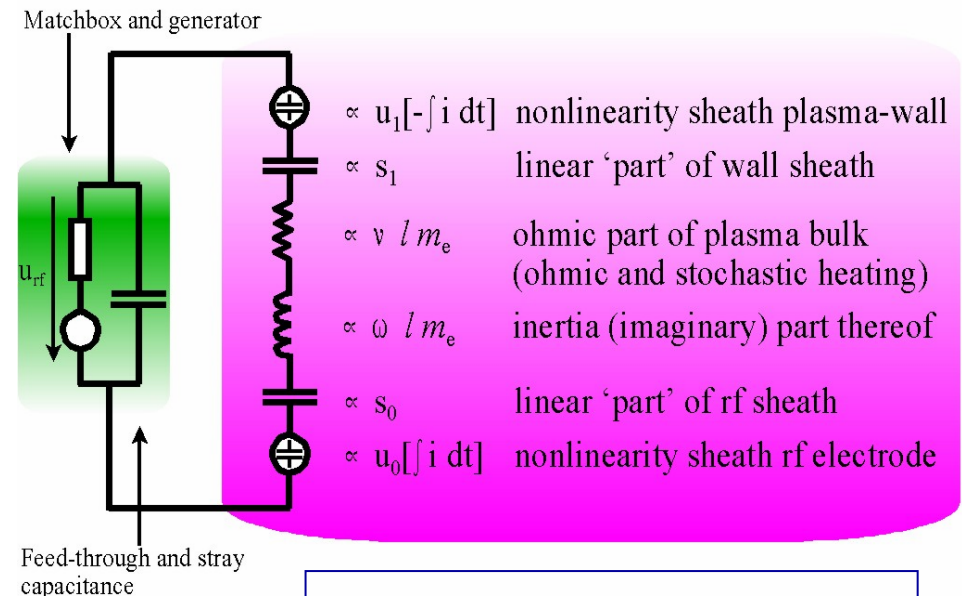


SEERS – an example of a measurement technique based on a physical plasma model

Self Excited Electron Plasma Resonance Spectroscopy



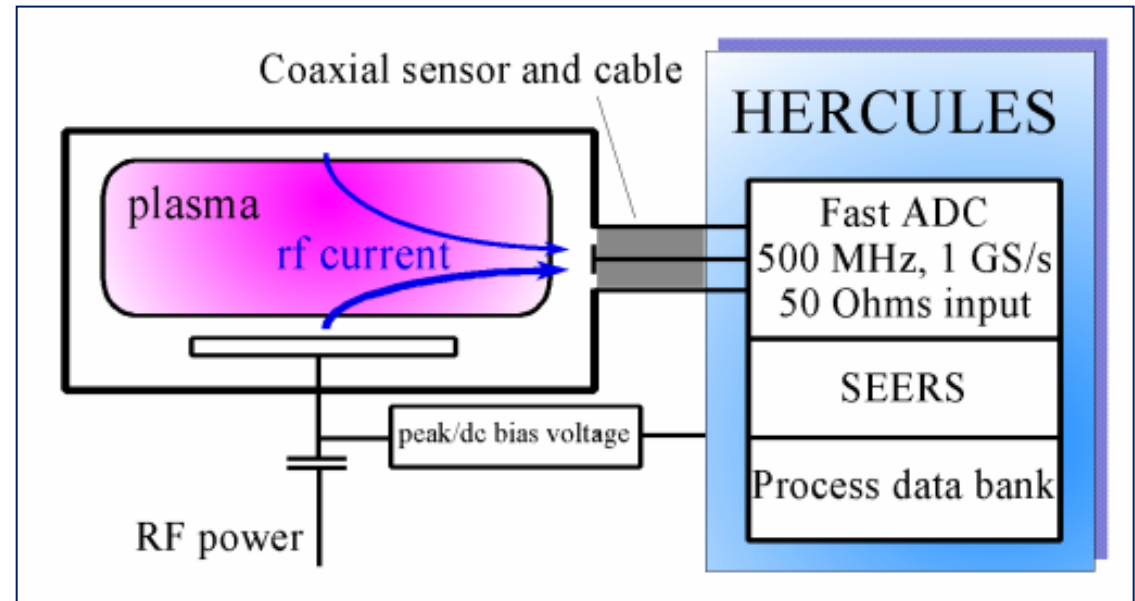
Electron collision rate
Electron density
Bulk power
DC bias voltage



- passive electrical method
- no impact on the plasma
- physical parameters
- integral measurement

Real time data reduction by model based measurement technique

Data compression
by factor 100

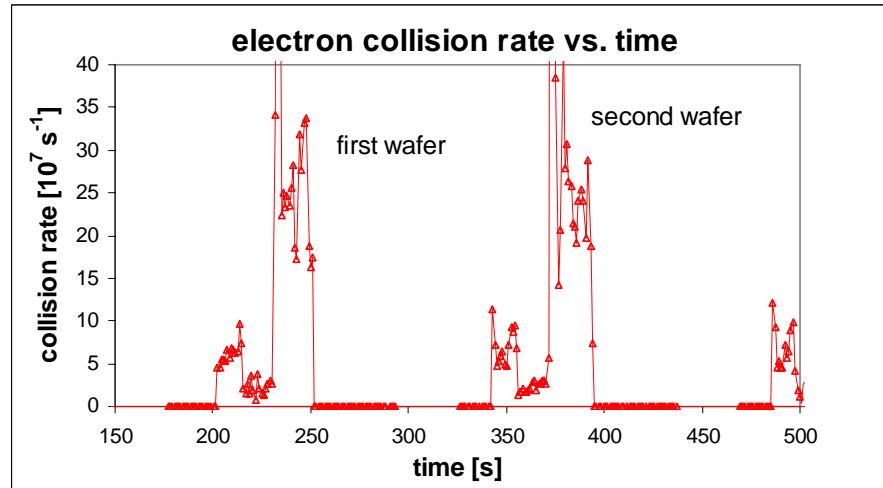


The plasma monitoring system HERCULES measures rf current and rf voltage (data volume 5 kByte/s). After a real time calculation, based on the plasma model SEERS, the mean values of plasma parameters are determined in real time and one mean value per second of each plasma parameter is stored (data volume 50 Byte/s).

Data reduction by using statistical key numbers



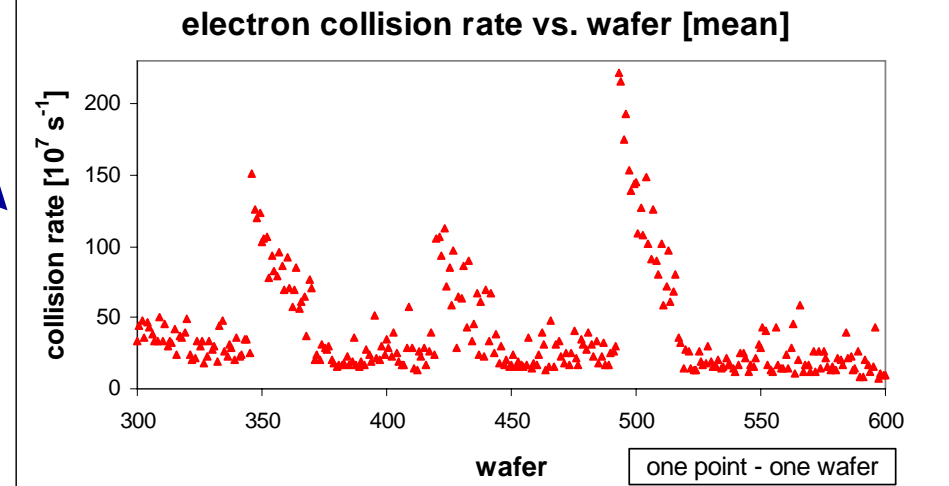
Data reduction by using statistical key numbers



The internal HERCULES and etch tool data bases contain time series from which statistical key numbers are extracted for each recipe step and each wafer.

Statistical key numbers:

| | |
|--------|--------|
| mean | median |
| stddev | IQR |
| min | max |



Data reduction by using complex process parameters



APC - process model

Input

measurable

- RF power generator output
- Cooling temperature
- Pressure
- Gas flow
- ...

Input (perturbation)

usually not measurable

- RF power chamber input
- Surface temperatures
- Polymer gas adsorption
- ...

Process Behaviour (Black Box)

$$R = f(F_n)$$

Output (Responses)

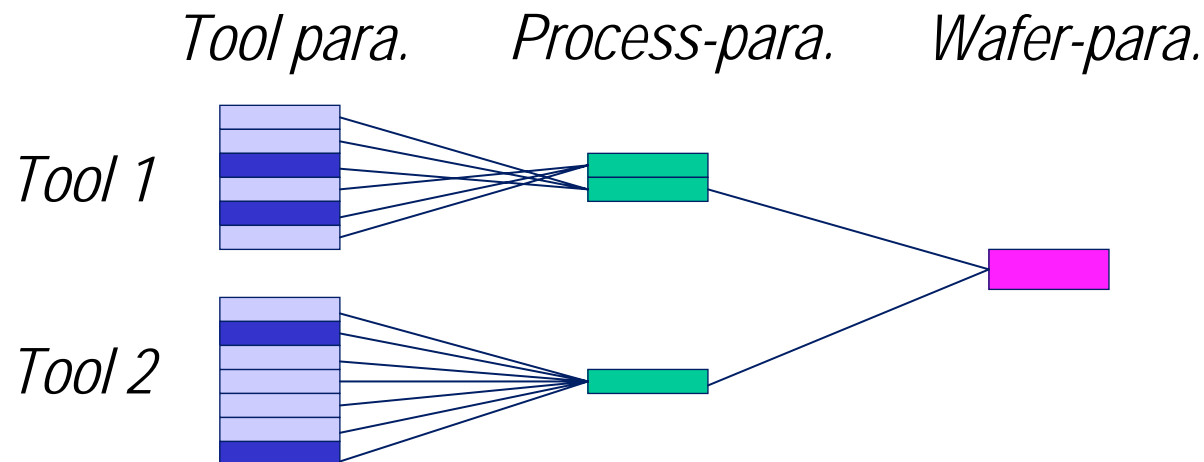
Yield

Electrical Parameter



Data reduction by measuring of complex process parameters

- The number of parameters, checked regularly at each tool or process, can be reduced by monitoring of complex process parameters, which indicate tool and wafer conditions, e.g. endpoint time or plasma parameters.
- Stable values of these complex process parameters indicate stable process condition.
- In case of process variations additional analysis of tool and wafer parameters is needed to identify the process change reasons in detail.



Data reduction by using model based data analysis – Data Mining

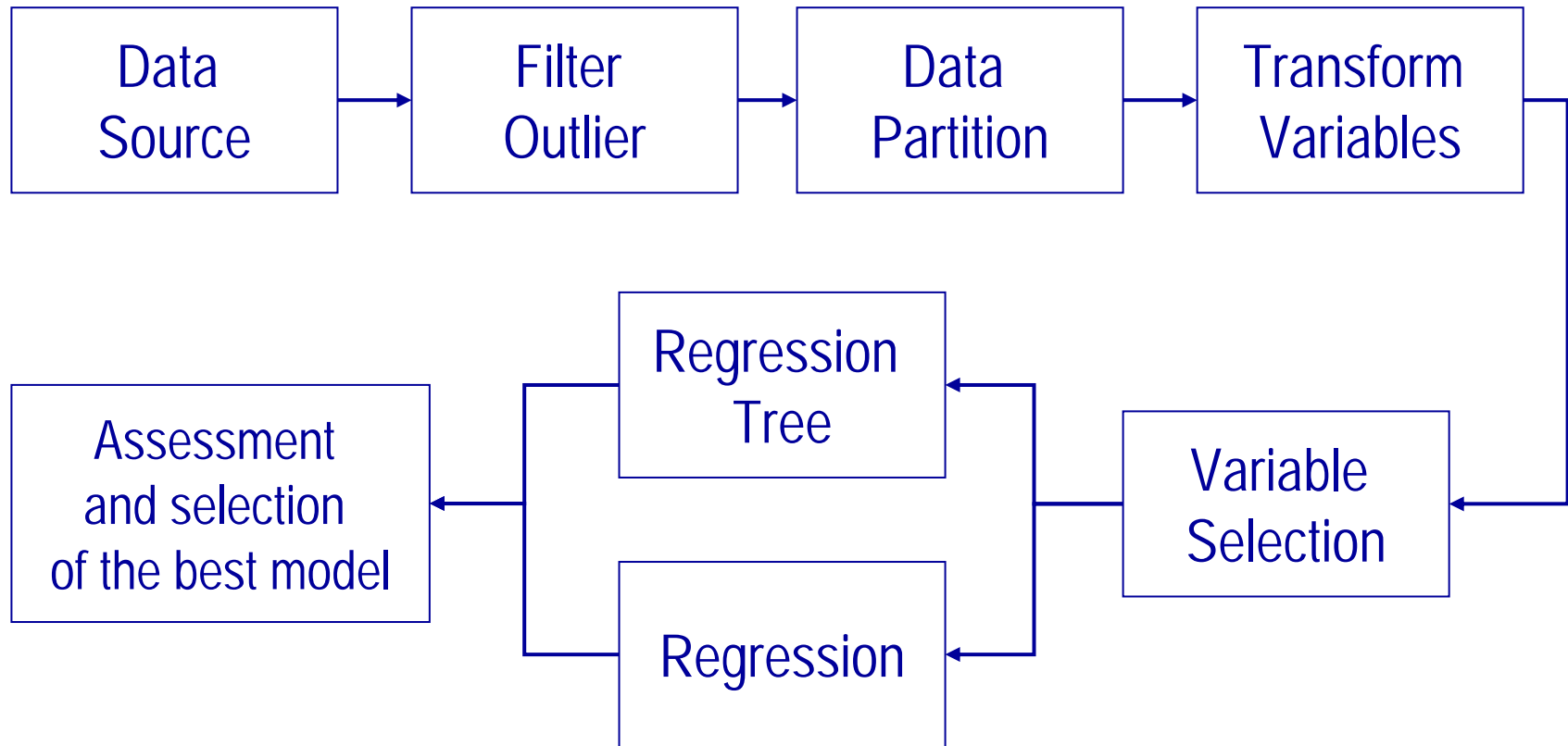


Data Mining: data preparation & predictive modelling

- Data Mining - Advanced methods for exploring, selecting and modelling relationships in large amounts of data
 - passive process analysis
 - large sample amounts of historical („dirty“) data
 - „fishing“ for p-values / find previously unknown pattern
- Data Mining work flow includes
 - Exploring data (filter outlier, data transforming, variable selection and elimination of redundancies a.o.)
 - Fitting of a predictive model using regression / decision trees / neural networks assessment and selection of the best



Data Mining work flow

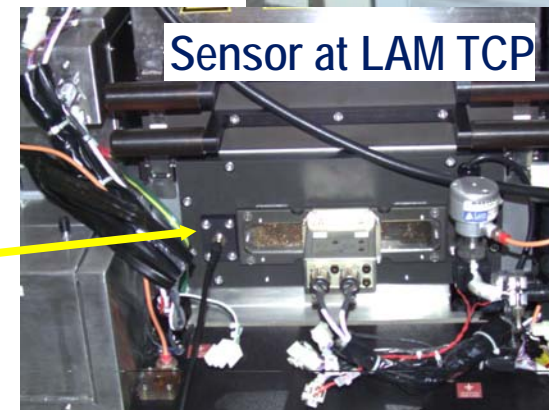


Application of model based data analysis to gate stack etch at LAM TCP



Measurement of plasma parameters for gate stack etch at LAM TCP

- Gate stack etch at LAM TCP:
 - Main etch: Cl , HCl , NF_3 - chemistry
 - Over etch: HBr , He/O_2 - chemistry
- Experimental data obtained by variation of standard recipe
- Historical data obtained by measurement of:
 - more than 25.000 wafers of
 - DRAM products
 - and logic products



Experimental data

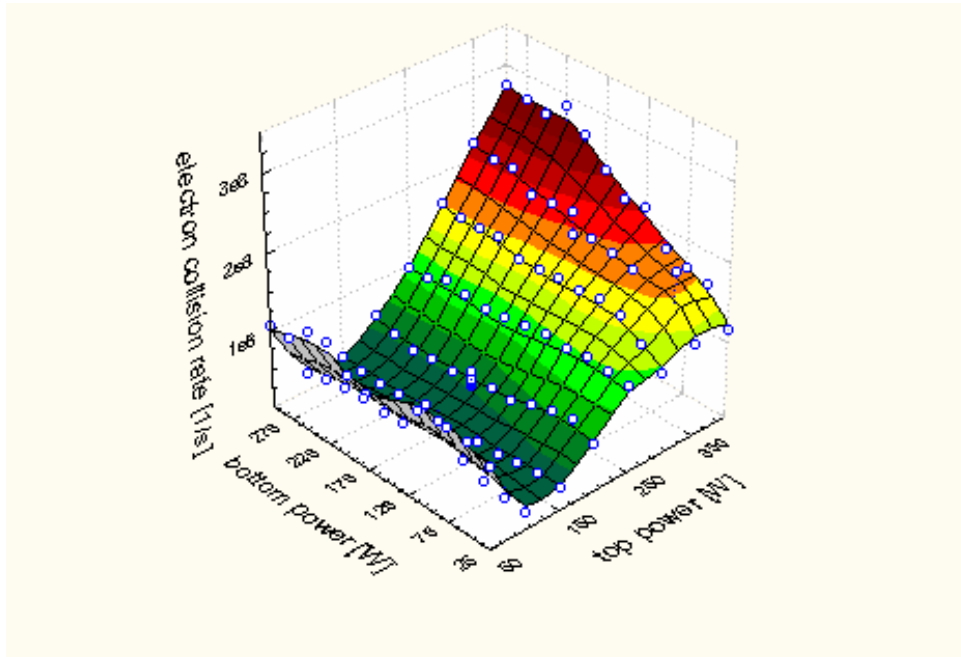


Experimental data:

Variation of standard gate stack etch recipe

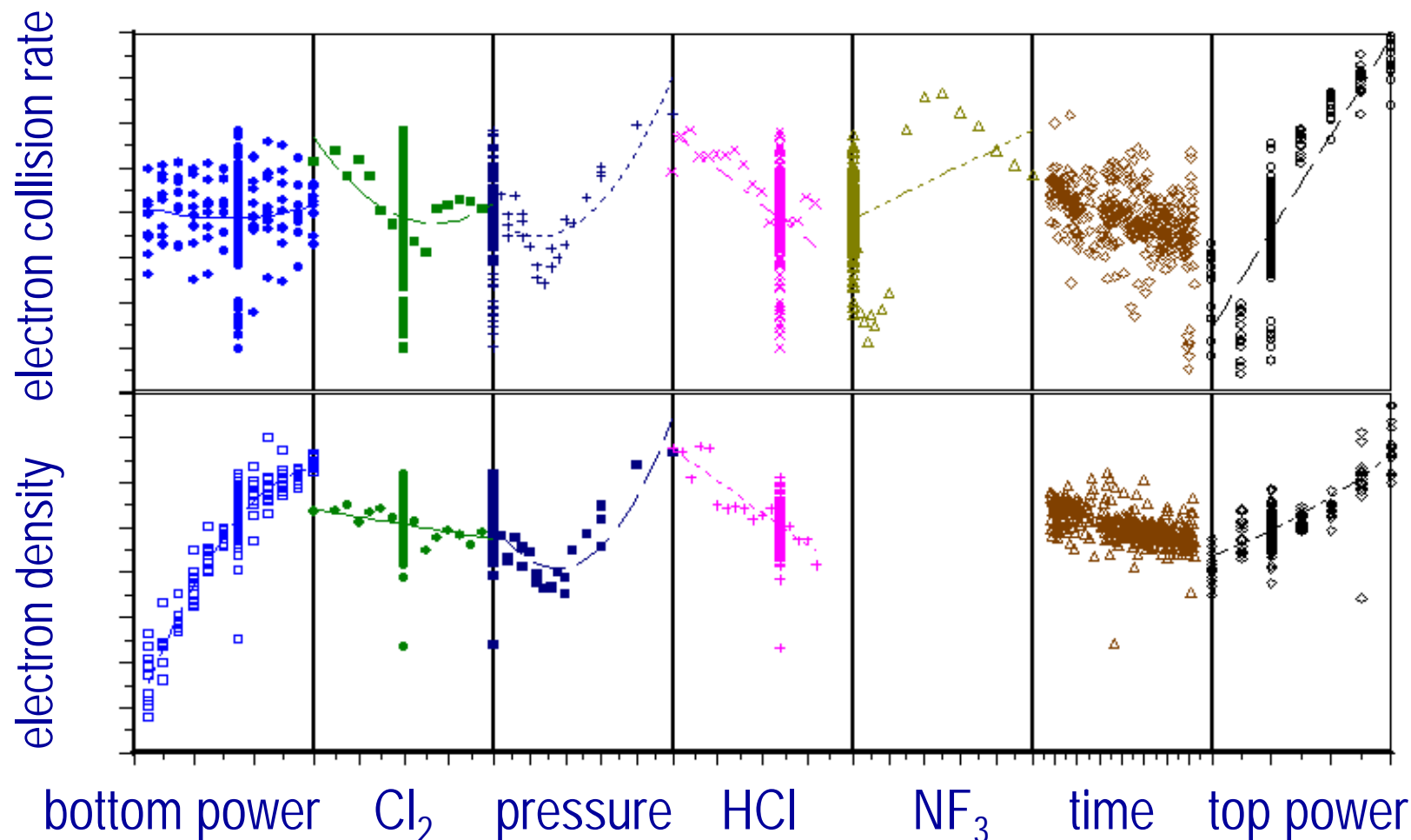
- Experimental data were obtained by variation of the standard gate stack etch recipe at LAM TCP on blanket test wafers to find correlations between plasma parameters and tool parameters.

Gate stack etch at LAM TCP, main etch
electron collision rate vs. rf power [mean]



- Variation of:
 - rf top power
 - rf bottom power
 - pressure
 - gas flow
- Separately for main etch and over etch
- Analysis with a second order approximation

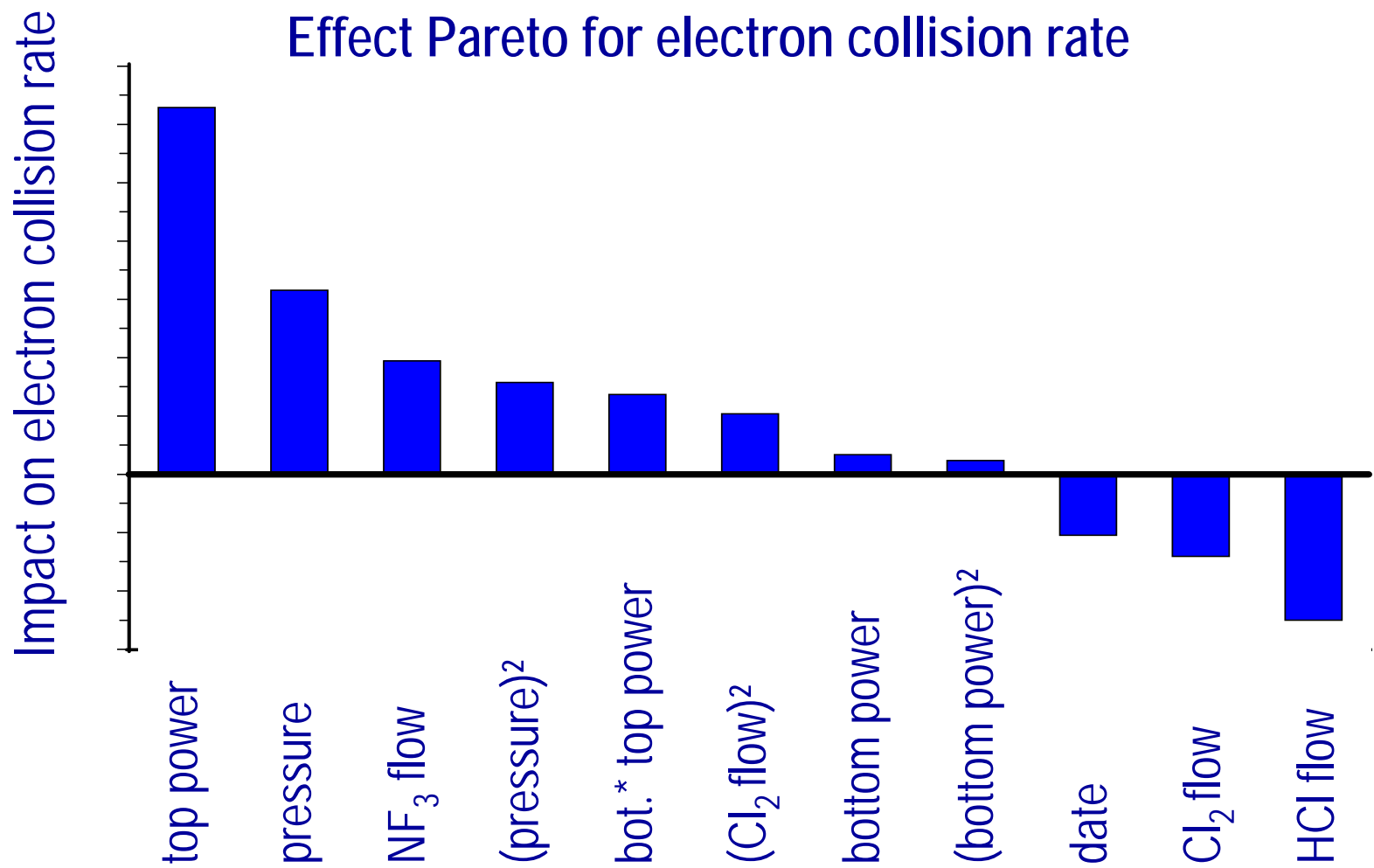
Gate stack main etch: Correlation between plasma parameters and tool parameters



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Gate stack main etch: Correlation between plasma parameters and tool parameters, cont.



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Discussion of correlation between plasma parameters and tool parameters

- Main impacts on electron collision rate:
 - TCP top power
 - pressure
 - HCl flow
 - NF_3 flow
 - Main impacts on electron density:
 - bottom power
 - TCP top power
 - pressure
 - HCl flow
- A significant drift of the chamber conditions during the experiments is indicated by:
 - small, but significant impact of the date of the measurements
 - large variation of plasma parameter values at center experiment results
 - This drift of the chamber conditions can be explained as an impact of not measurable input parameters on the complex process parameters electron collision rate and electron density.

Historical data

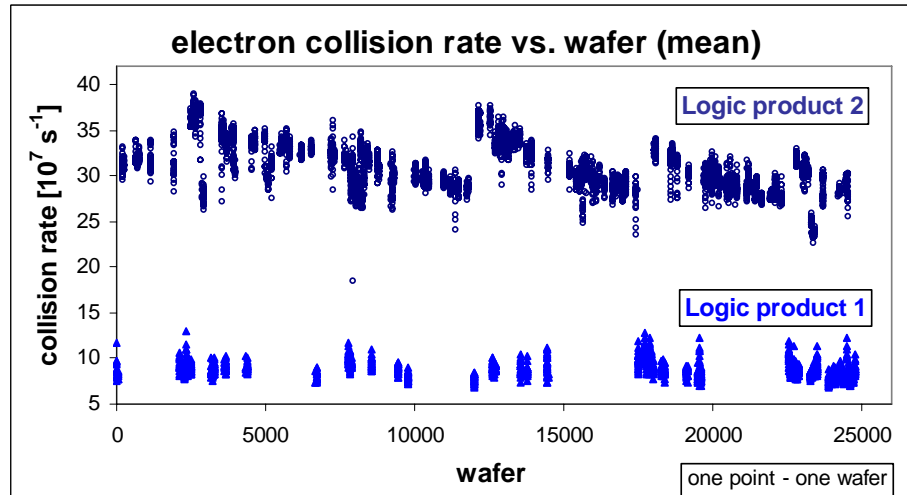


Measurement of plasma parameters for DRAM and logic product wafers

- Historical data were obtained by measurement of plasma parameters at one LAM TCP chamber for more than 25.000 wafers of several DRAM and logic products.
- Model based data analysis was performed for more than 4.000 wafers of one DRAM product to find correlations between
 - plasma parameters and tool parameters
 - plasma parameters, electrical data, and yield
- During the period of these measurements a high and stable yield was achieved. The final electrical tests did not indicate any problem concerning the gate stack etch at the observed chamber.



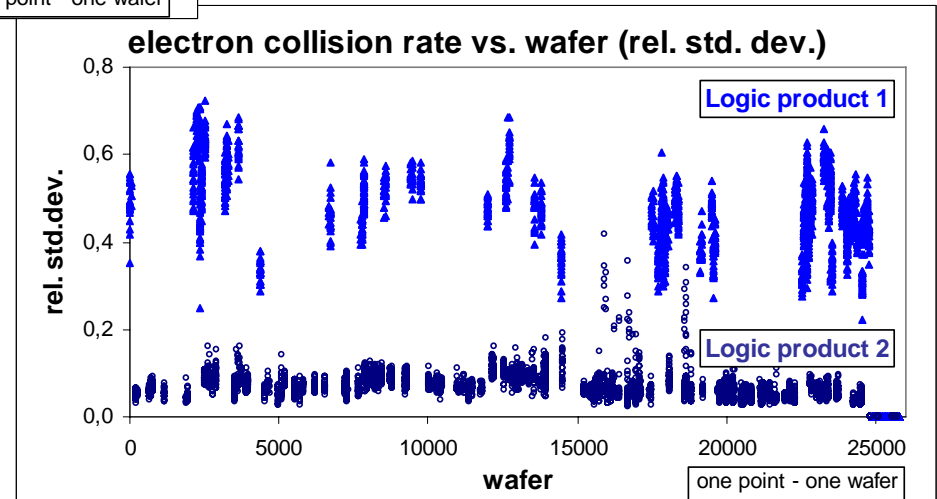
Gate stack etch at LAM TCP: Main etch



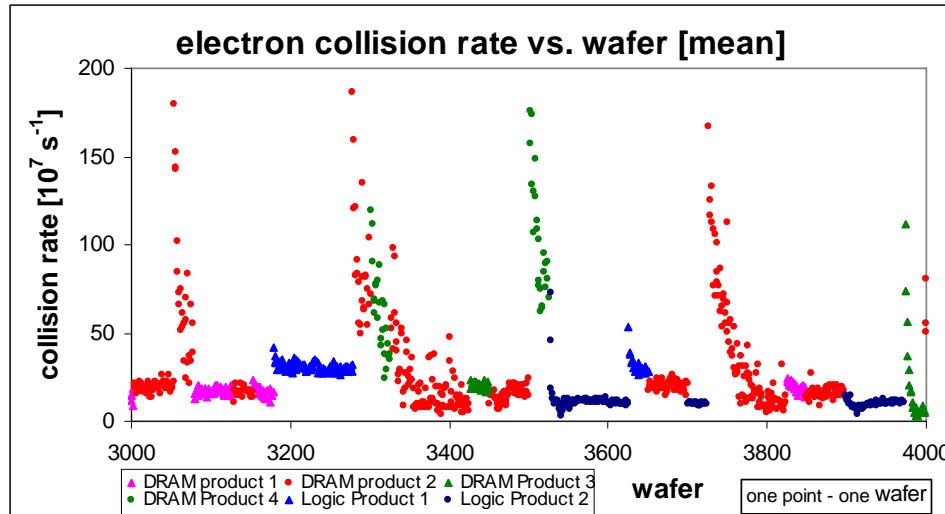
Chamber impact on electron collision rate:
Mean of electron collision rate indicates chamber drift between wet cleans.

Wafer impact on electron collision rate:
Logic product 2 has:

- higher mean value
- lower standard dev. of electron collision rate.



Gate stack etch at LAM TCP: Over etch



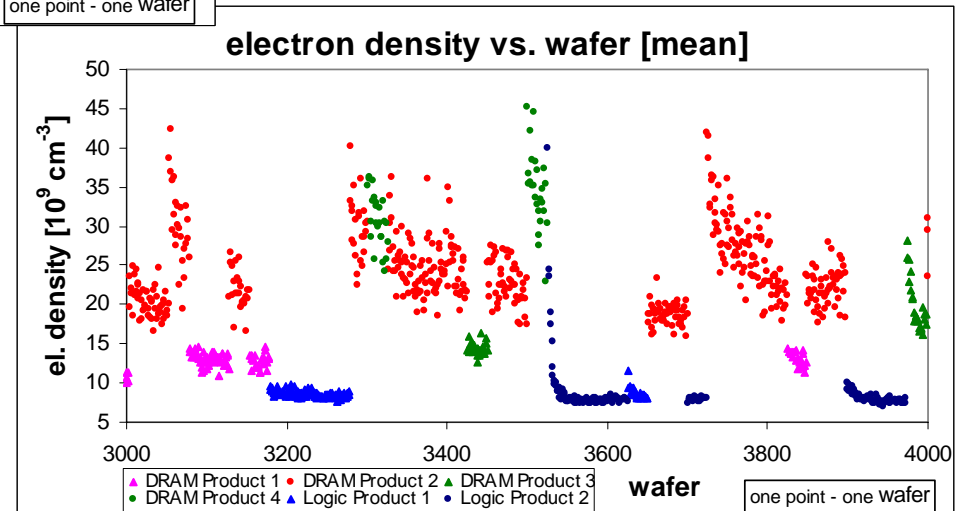
Chamber impact on electron collision rate:

- Short term drift
- Conditioning effect



Wafer impact on electron density:

- Product
- Open area
- Pre processes



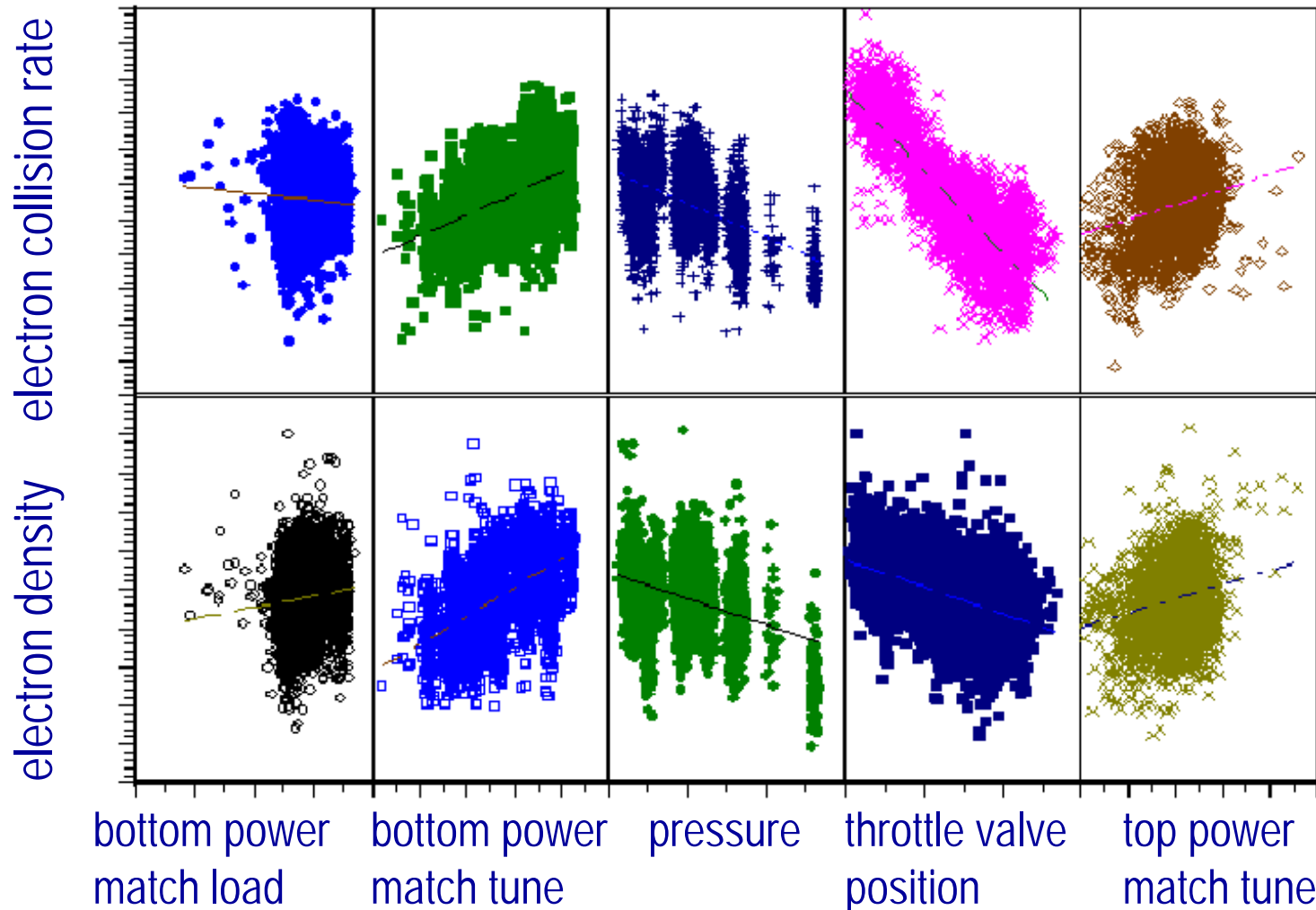
Gate stack main etch - over etch:

Discussion of the measurement results

- Electron collision rate and electron density as complex process parameter show tool impacts and wafer impacts on the process.
- At both etch steps the plasma parameters indicate:
 - Product impact on the process
 - Product depending process stability, wafer to wafer, lot to lot
- The drift of the chamber conditions depends on the etch step:
 - Long term drift between wet cleans at main etch
 - Short term drift at over etch
- Conclusions: Process control should be done separately for
 - Main etch and over etch → find the most important step
 - Different products → select the most important products



Gate stack main etch: Correlation between plasma parameters and tool parameters



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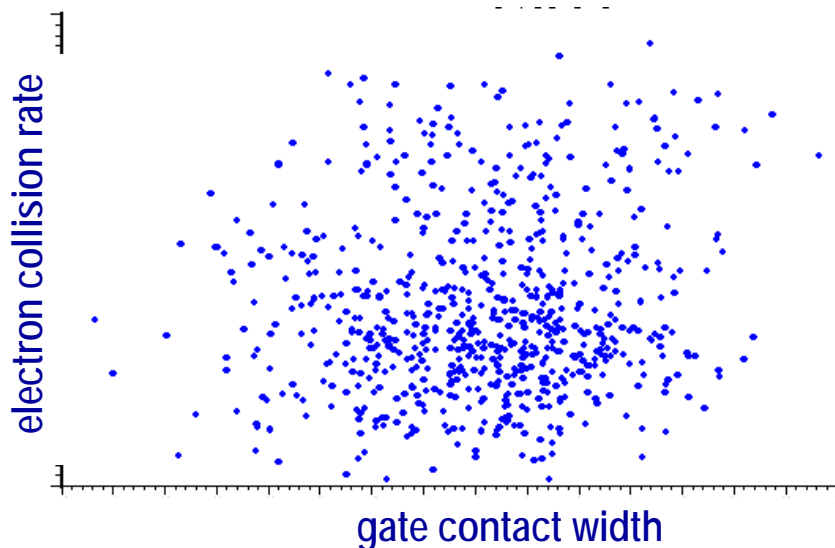
Main etch: Discussion of correlation between plasma parameters and tool parameters

- The historical data on product wafers discussed here were of course sampled keeping all measurable tool parameters constant. Process variations are caused by not measurable inputs. The tool tries to compensate these variations of input parameter, therefore drifts of measurable tool parameters occur.
- Main correlations between tool parameters & plasma parameters are seen for:
 - throttle valve position and pressure
 - top power match tune and bottom power match tune
- These correlations agree with the results of the process variation (see experimental data). Some tool parameters are influenced by known process relevant tool effects and slightly by process changes.
- For process monitoring a complex process parameter can be used instead of several tool parameters.



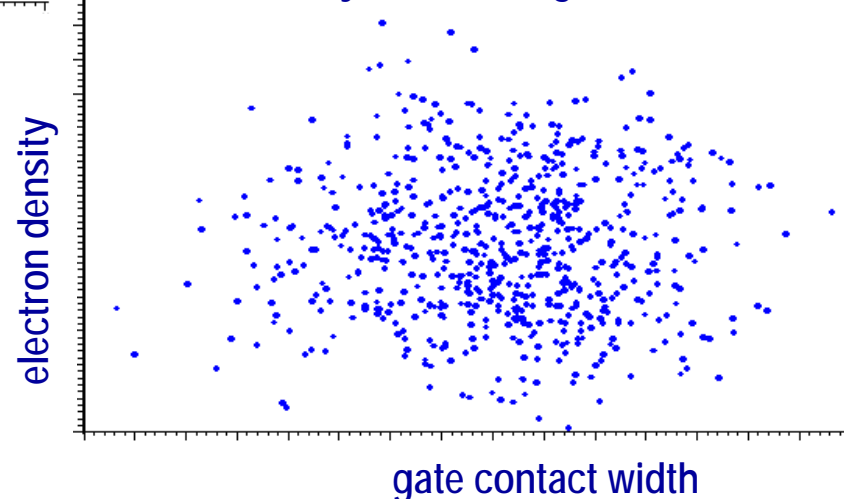
Gate stack main etch: Correlation between plasma parameters and gate contact width

electron collision rate [mean] vs. gate contact width



- The gate contact width is calculated by electrical measurements.
- Gate stack etch is an important influence on gate contact width.

electron density [mean] vs. gate contact width



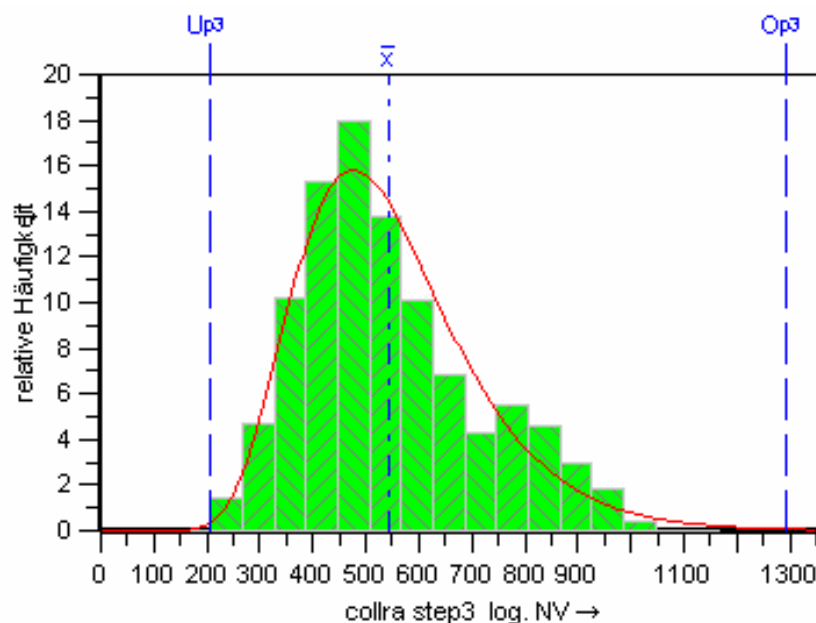
- The analysis of more than 4.000 wafers of one DRAM product did not show any significant correlation between plasma parameters and electrical data.

Discussion of historical data analysis

- Significant correlations between plasma parameters and tool parameters were detected for process variations on test wafers and during long term measurements on product wafers.
- Significant process drifts were monitored by the plasma parameters during long term measurements on product wafers.
- During the measurement period high yield and stable electrical parameters were achieved. Significant correlations were not obtained between plasma parameters, electrical data, and yield.
- Conclusions: The process window for these products at this tool was large enough during the measurement period. The process runs well.
 - We observed the „normal noise“ of the process on that tool.
 - The measurement technique is very sensitive. We can expect significant signals in case of serious process problems.
 - Calculation of control charts can be done.

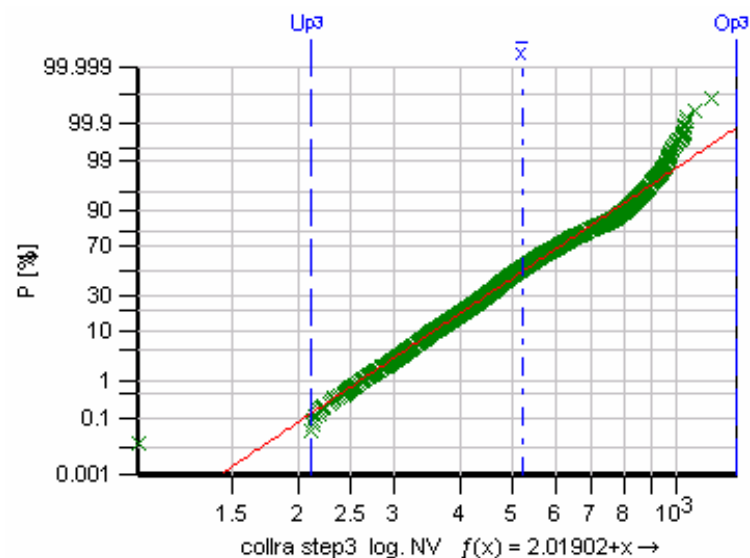


Gate stack main etch: Calculation of control charts for electron collision rate



- The values of the mean electron collision rate are not normally distributed.

- Therefore a Pearson control chart was calculated.

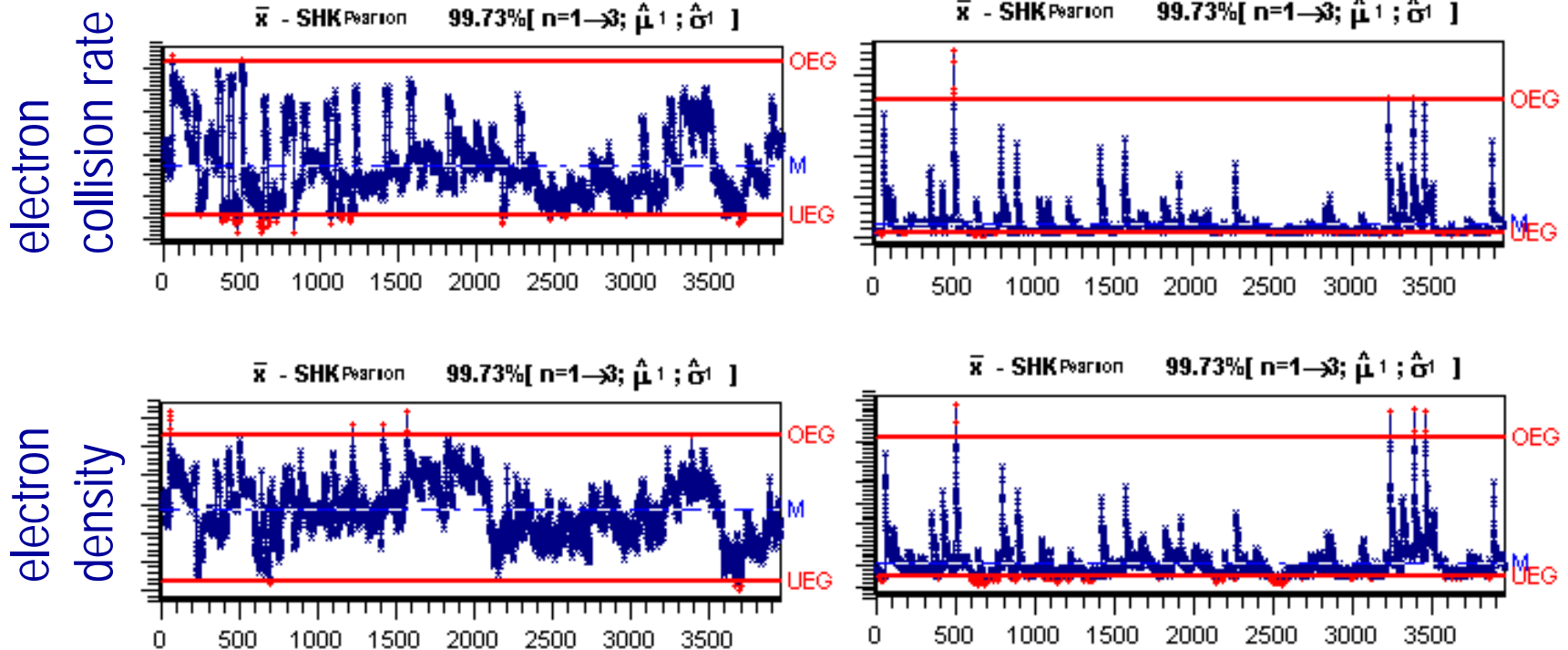


Gate stack etch: Control charts for electron collision rate and electron density

The control charts must be calculated for main etch and over etch separately.

Main etch

Over etch



Summary

- Data reduction for Advanced Process Control in high volume production is demonstrated for gate stack etch in LAM TCP by:
 - measurement of plasma parameters with the model based measurement technique SEERS
 - calculation of statistical key numbers
 - model based analysis with data mining techniques
- Experimental data, obtained by variation of the standard recipe, and historical data, recorded for more than 25.000 product wafers show correlations between plasma parameters and tool parameters.
- During the measurements a high and stable yield was obtained. Therefore correlations between plasma parameters, electrical data, and yield were not found and control charts for plasma parameters were calculated.
- Plasma parameters control charts supply alarm levels for real time monitoring of gate stack etch process at LAM TCP.

