Tool Comparison at GC Stack Etch in LAM TCP Using Plasma Parameters (SEERS)

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diploma thesis

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in cooperation with Infineon Technologies GmbH & Co. OHG

Center for Development and Innovation

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Motivation

- Comparison of two plasma etch chambers LAM TCP 9400 SE at Gate Conductor Stack Etch
- Critical etching of gate oxid found at finished products depending on chamber ➔ find reason
- Investigate impacts of process parameter variations on in-situ plasma parameters electron collision rate and electron density
- Find correlations between plasma parameters and measurements as etch rate, uniformity
- Monitoring of high volume production

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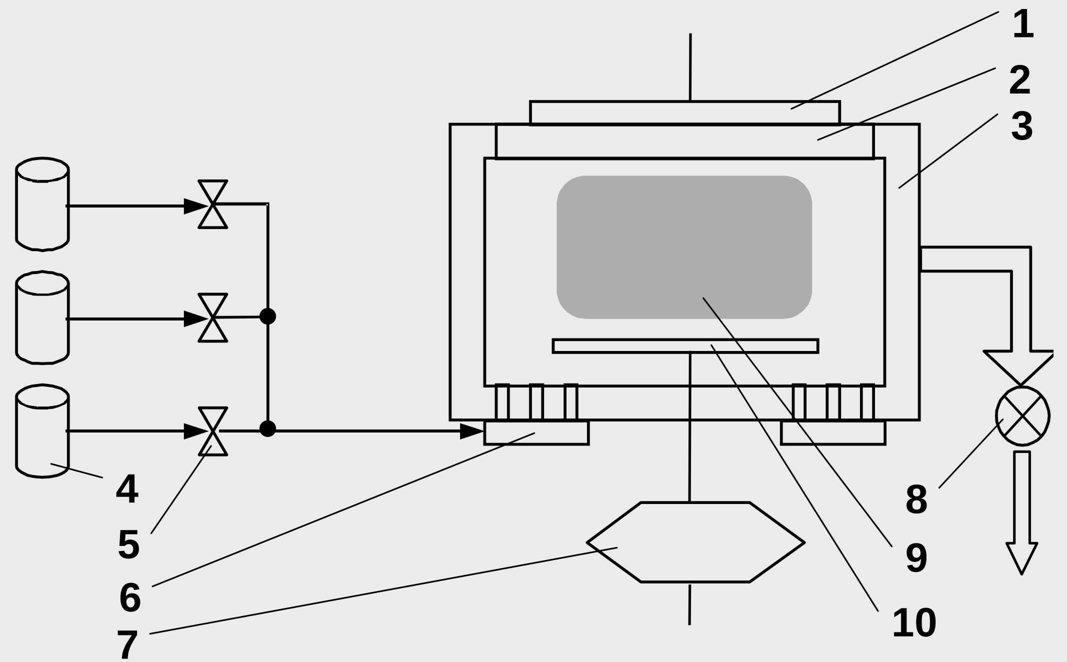
12.12.2000

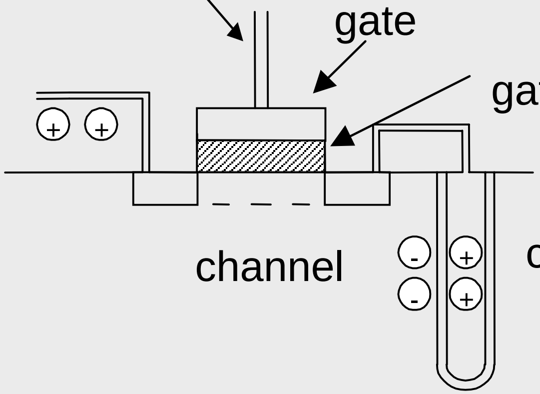
Principle plasma etch (LAM TCP)

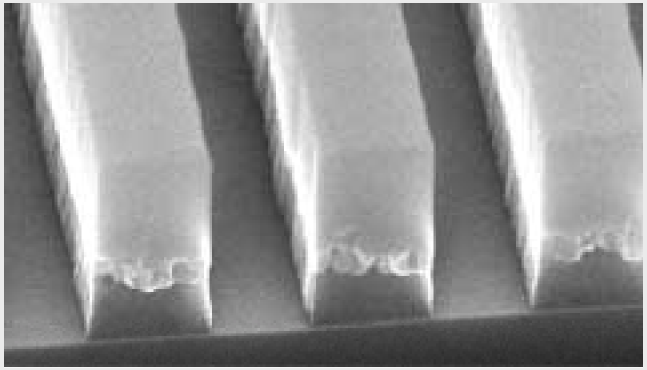


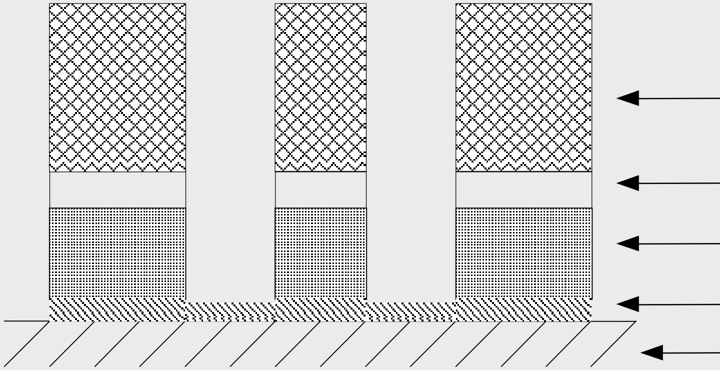
- <u>LAM TCP 9400 SE:</u>
- 1 - wafer - plane - chamber
- low pressure at chamber
- inductive RF power coupling (= Top Power)
- additional power capacitively coupled (Bottom Power)
- reactive gases flow as mixture into chamber

- plasma:
  - low pressure
  - high density
  - asymmetric RF discharge

GC Stack - Principle







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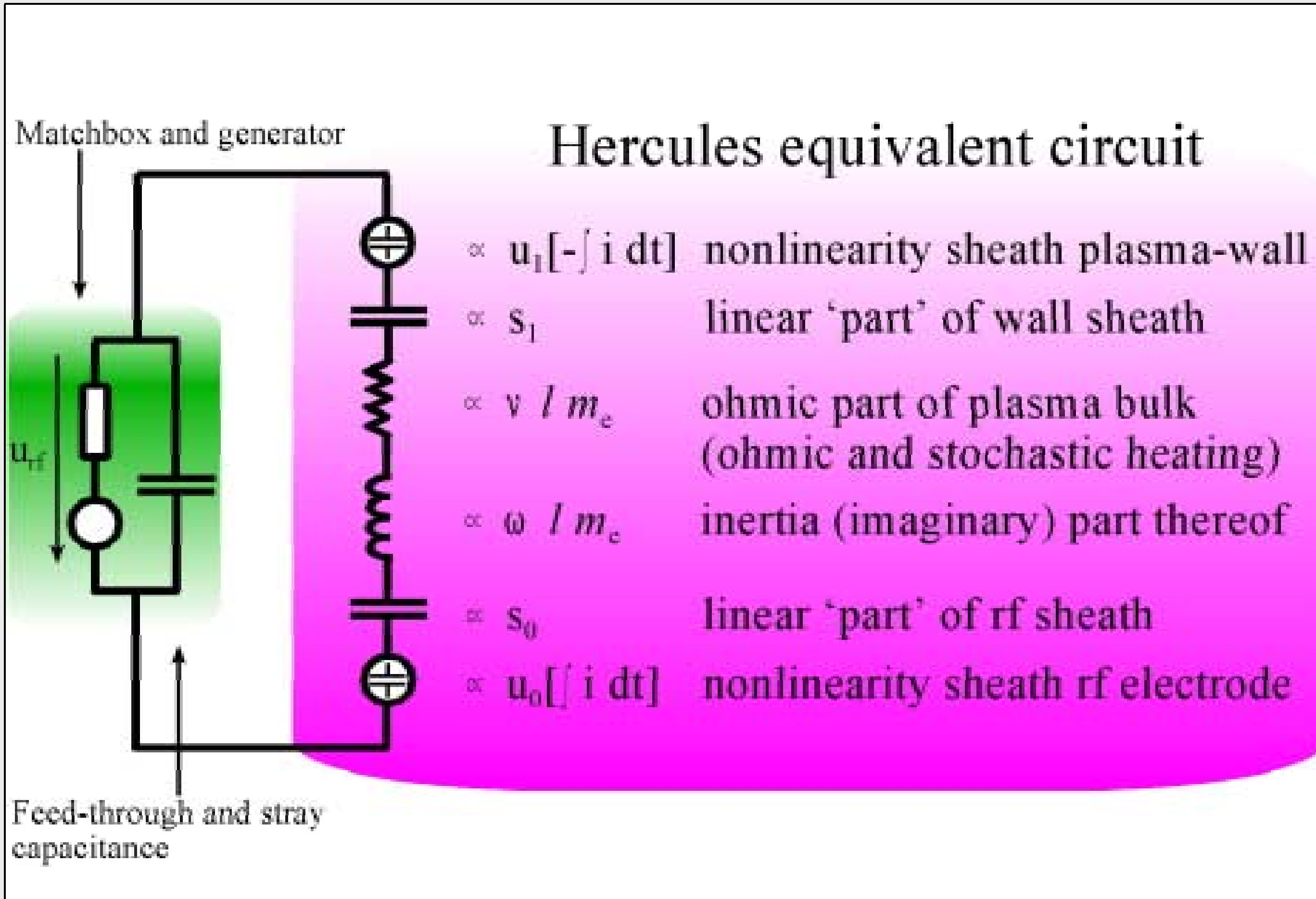
SEERS - electrical model of RF discharge



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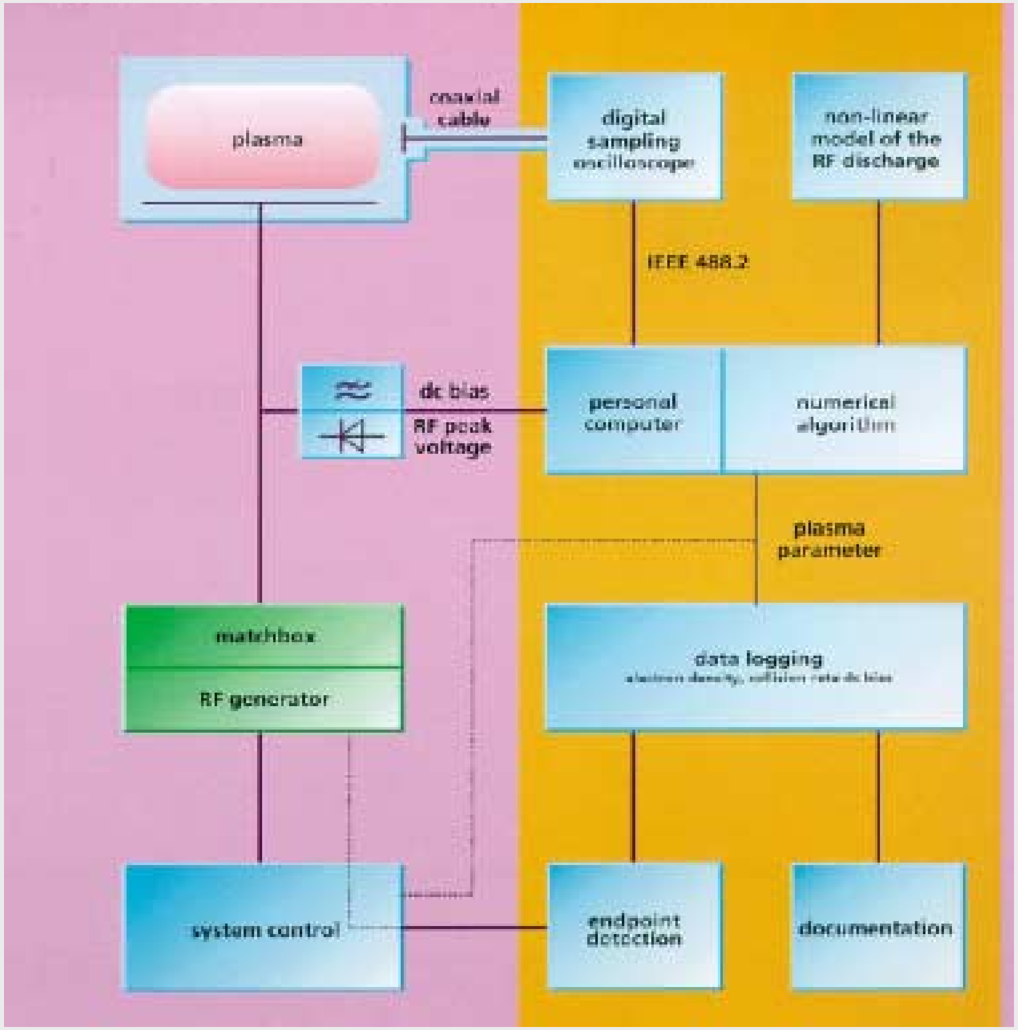
2nd Workshop on Self Excited Electron Plasma Resonance Spectroscopy, 11th-12th December 2000, Dresden, Germany

Principle of HERCULES measurement system



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Plan of experiments

parameter	from	to	step width	Test Etch duration (s)
pressure	5 mTorr	30 mTorr	1; 2; 5 mTorr	30
top power	50 W	400 W	50 W	20
bottom power	0 W	300 W	25 W	20
Cl_2-flow	0 sccm	80 sccm	5 sccm	25
HCl- flow	0 sccm	160 sccm	10 sccm	25
O_2- flow	0 sccm	50 sccm	1; 5 sccm	25
NF_3- flow	0 sccm	50 sccm	1; 2; 5 sccm	25

- measured values:
  - electron collision rate
  - electron density
  - etch rate, uniformity at several tests
- wafer types:
  - mono Si wafer, raw
  - poly Si wafer for etch rate & uniformity

- process characteristics:
  - process chemistry at main etch dominated by chlorine
  - competition between chlorine and fluorine species
  - competition between deposition and erosion depending on process conditions
- parameter variations:
  - changing one gas flow while leaving all others constant
  - pressure variation
  - power grid, remaining sizes under process conditions

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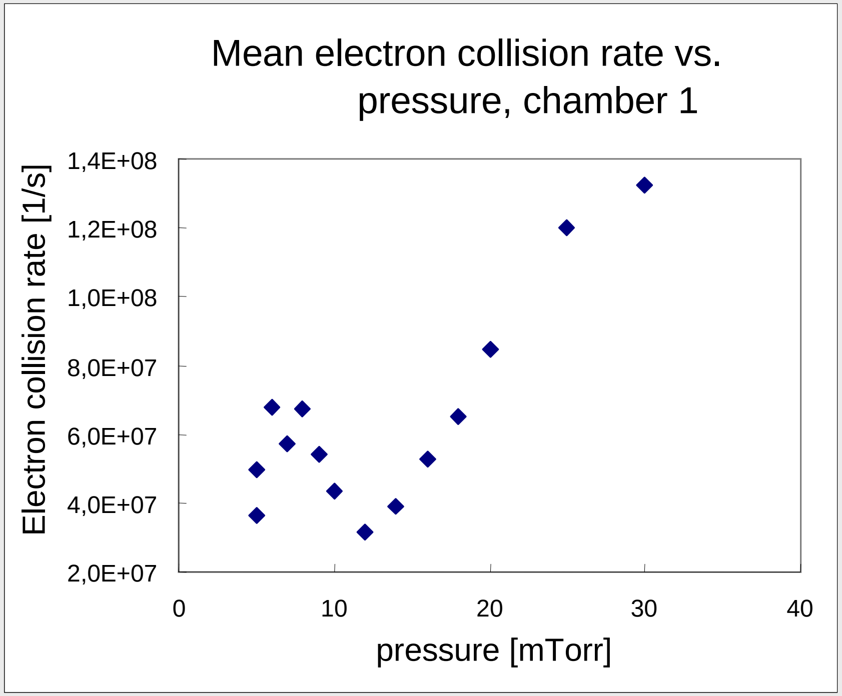
Results of parameter variations: Electron collision rate depending on pressure



- Pressure variation: collision rate shows nonlinear behaviour
- Distinction of domination by ohmic heating / stochastic heating possible (= different modi of power conversion into plasma)
- Saturation / maximum at even higher pressures estimated

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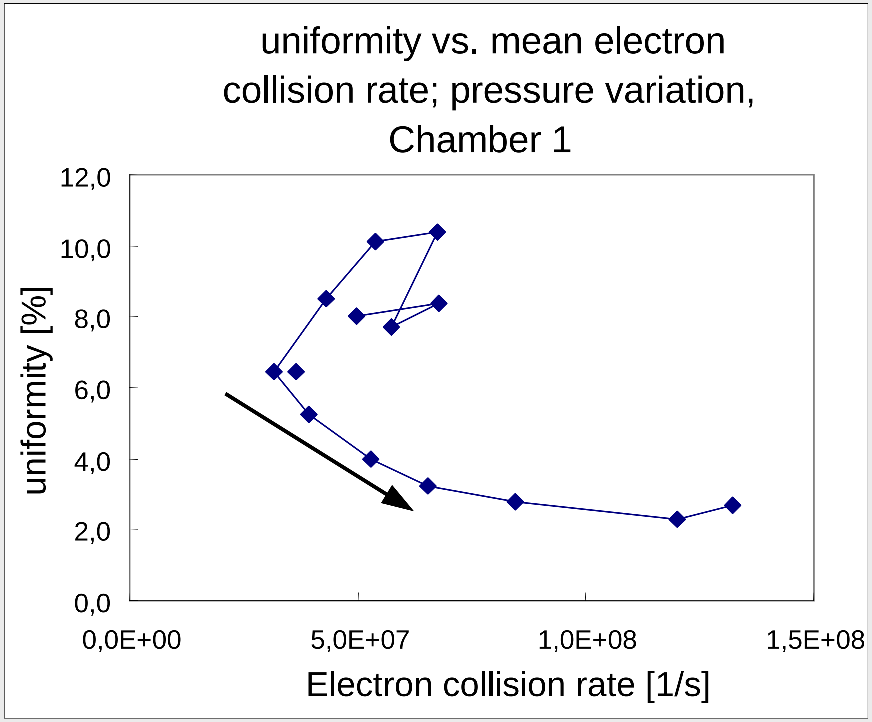
Results of parameter variations: Correlation between uniformity and electron collision rate



- Nonlinear behaviour of uniformity depending on mean electron collision rate
- No explicit function at whole parameter range

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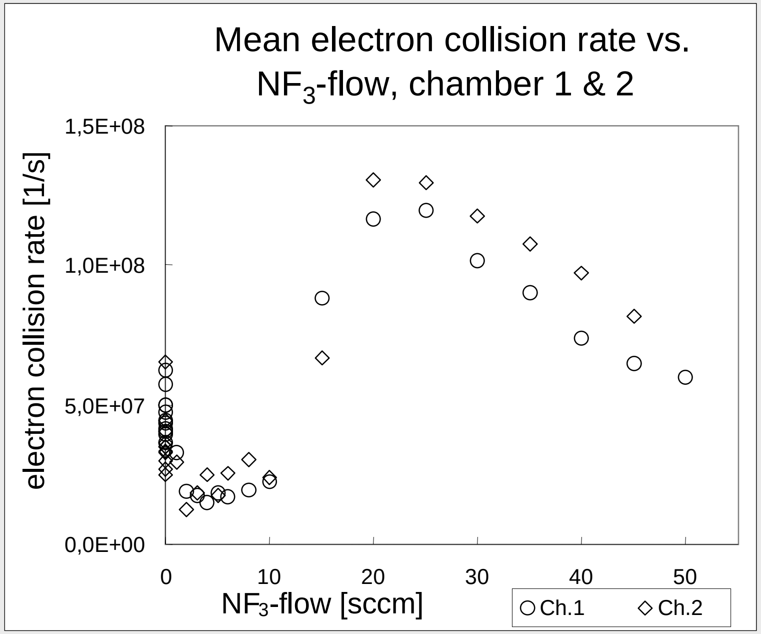
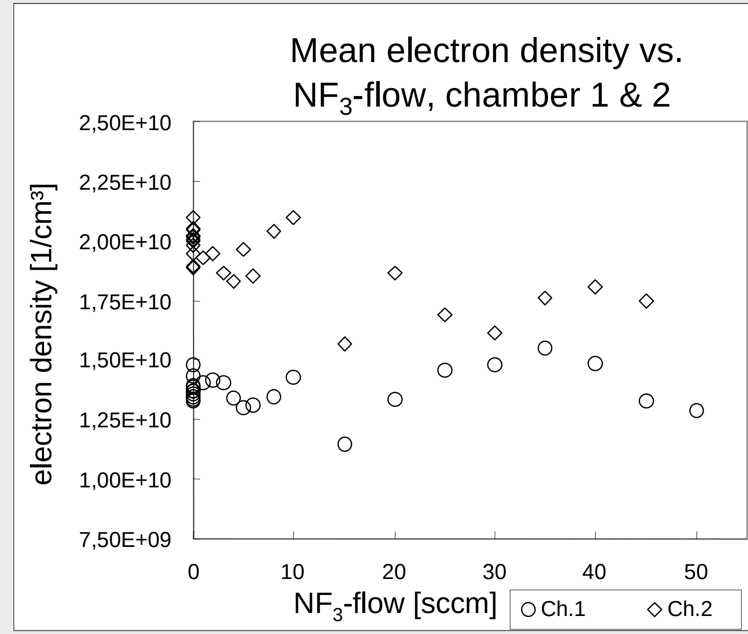
Results of parameter variations: Correlation between electron collision rate and NF_3 flow





- Using chamber several hours with chlorine chemistry exclusively
- after that input of NF_3
- Competition between chlorine and fluorine species (atoms, ions, radicals)
- Explanation for shown behaviour ?

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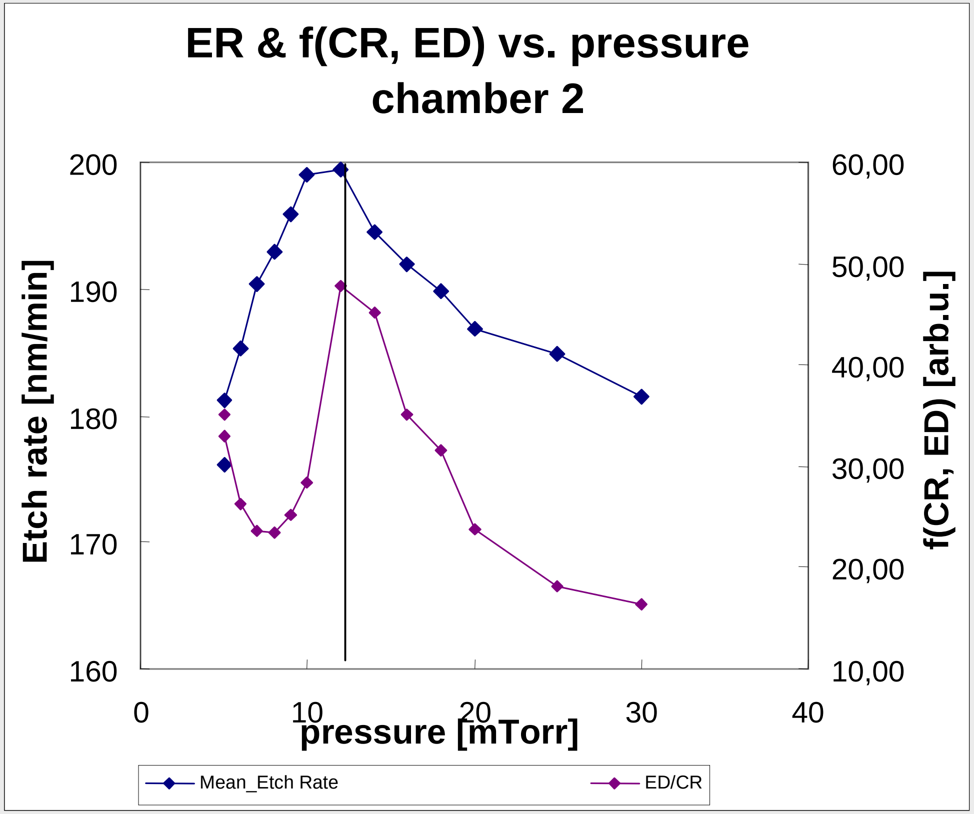
Results of parameter variations: Etch rate and plasma parameters depending on pressure

- Partly correlation between in-situ and in-line measurements possible (right part)
- Example: mean etch rate (blue) and quotient electron density / electron collision rate (purple) at pressure variation
- some more sizes seem to influence etch rate



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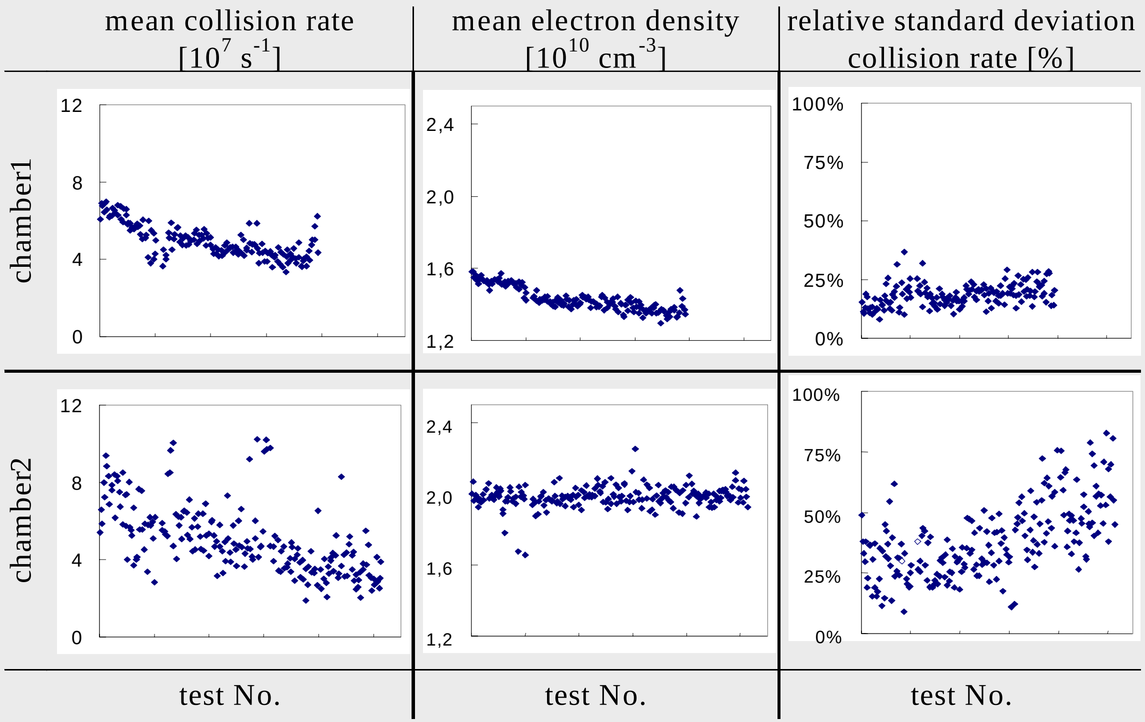
Results of chamber comparison: Long term drift of chamber conditions

Control tests during whole experimental time:



- All values at both chambers show drifts about whole time excepted mean electron density of ch. 2
- Ch.2: deviations of mean values are higher with increasing tendency
- During each parameter variation just small drifts

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Chamber comparison by electron collision rate depending on top power and bottom power

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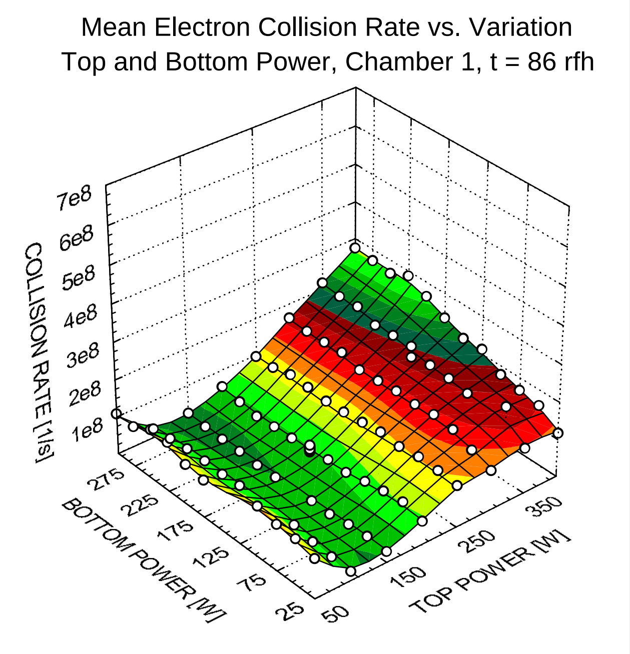
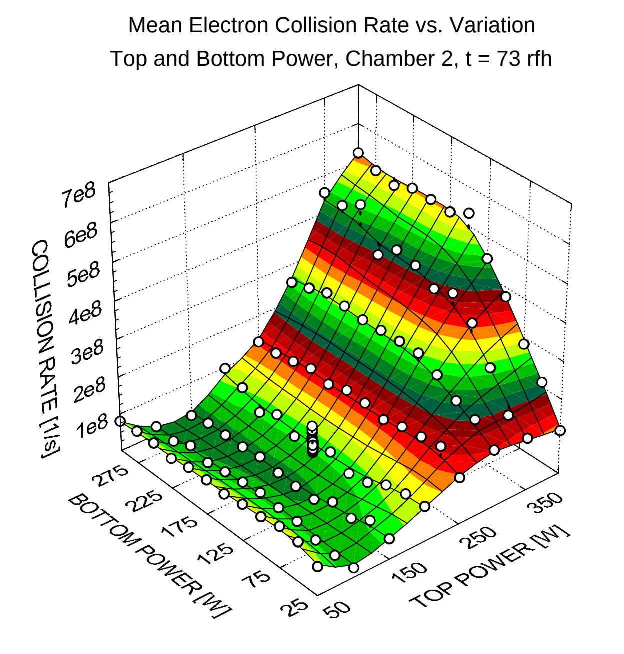


reference chamber



striking chamber

- No significant qualitative differences
- Quantitative difference in collision rate
- Interesting: local minimum along increasing bottom power
  ➔ separating ohmic + stochastic heating

Chamber comparison by electron density depending on top power and bottom power

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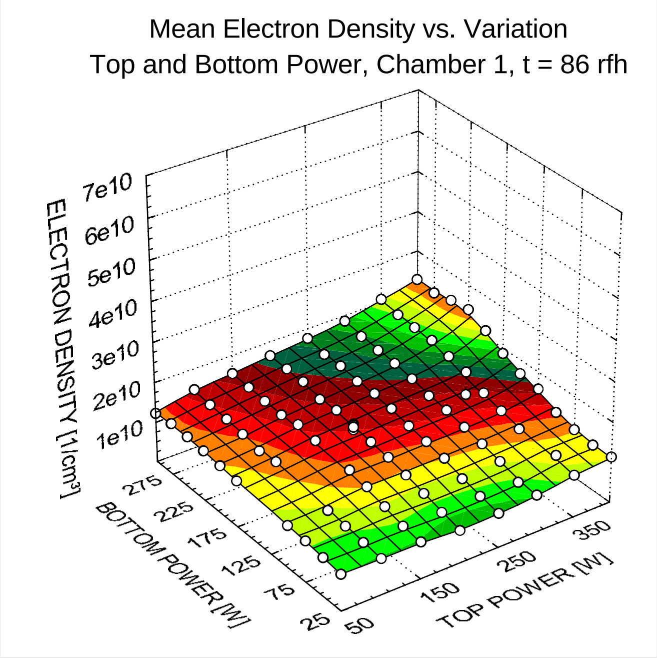
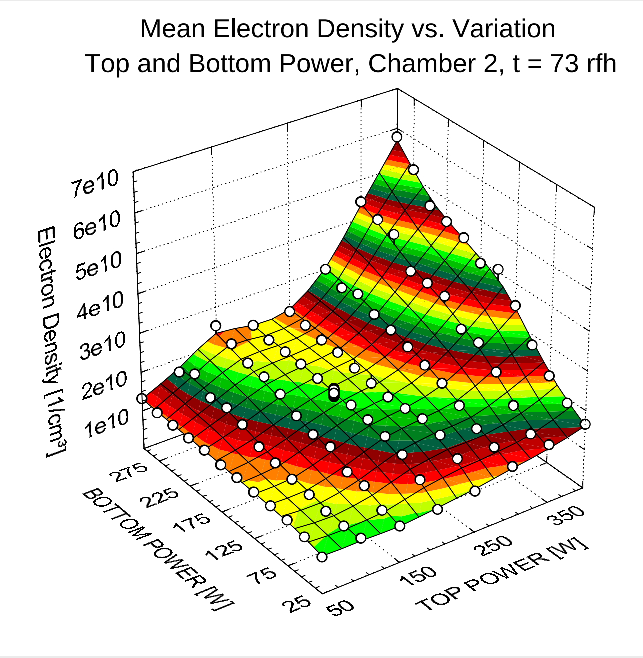


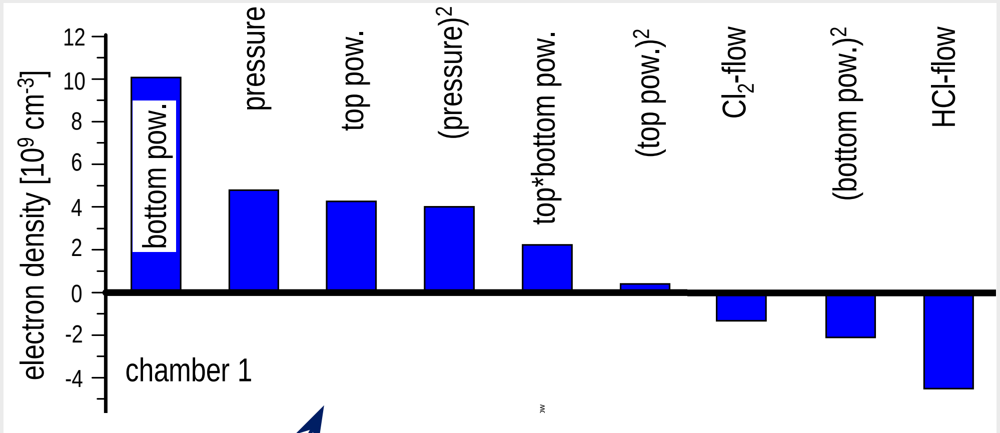
reference chamber



striking chamber

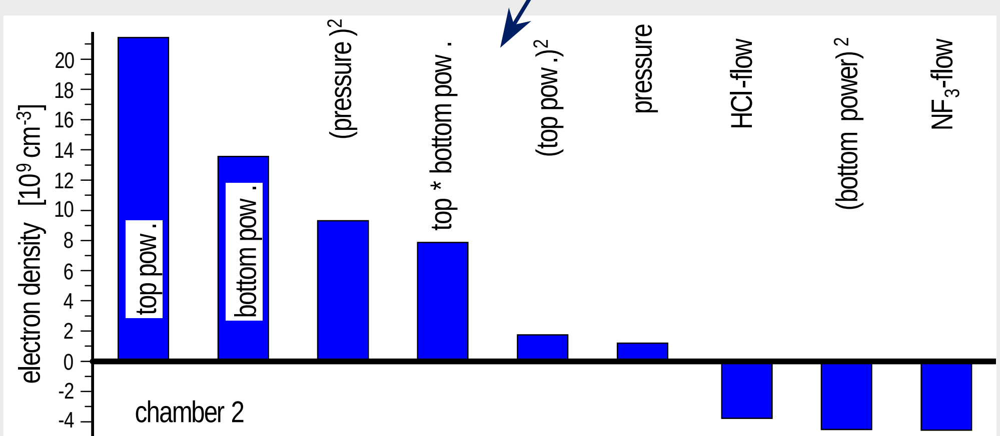
- Significant different shape and quantity at electron density area
- Hint for cause of chamber difference: power coupling ➔ hypothesis: top power

Results of chamber comparison - Pareto



reference chamber

striking chamber



proof by Pareto comparison:

- sequence and size of influences change chamber by chamber
- Top power has biggest influence on plasma parameters at striking chamber
- Pressure plays second role after powers
- Gas flows have just very little influence

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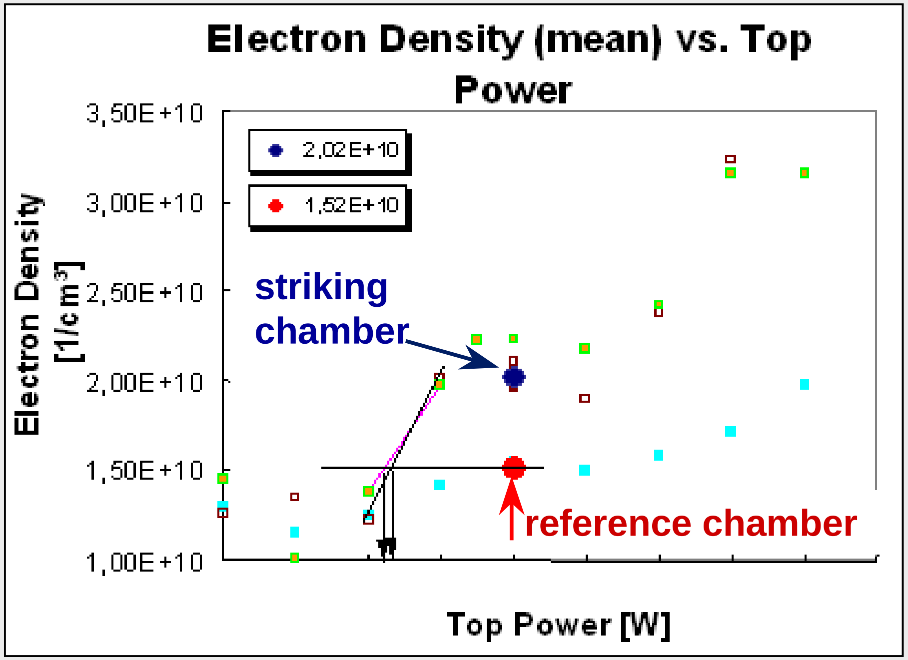
Application of electron density on RF power input calibration



- Idea: calibration of power dissipation by electron density measurement
- Problem:
  - strong nonlinearity, set point near local minimum at striking chamber
  - to achieve target value (reference chamber) halving actual value is necessary

- Strong nonliearity possibly caused by interaction of TCP power matchbox and bottom power matchbox
- Because of this strong nonlinear effect electron density could not be used for chamber matching,
- Hardware reason of local maximum must be fixed before chamber tuning

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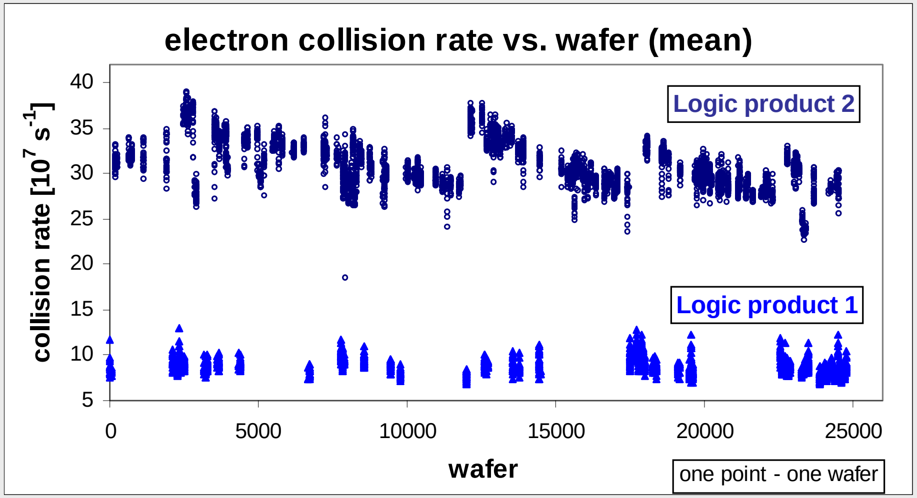
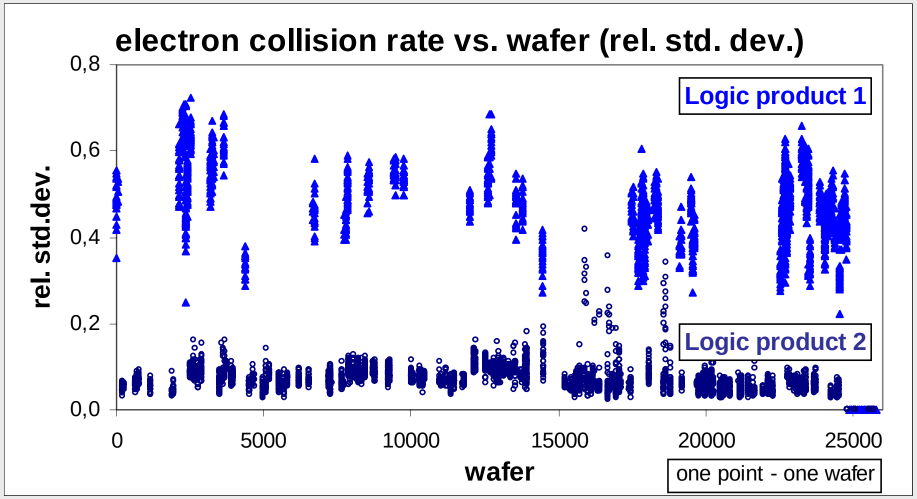
Results of production monitoring - main etch





- More than 25 000 product wafer were monitored
- Good results and high yields at all time
- Main etch step
- Means and relative standard deviations of wafers
- Two logic products
- Products clearly distinguishable ➔ recipe and wafer impact
- Chamber drift during wet clean cycle visible ➔ influence of chamber

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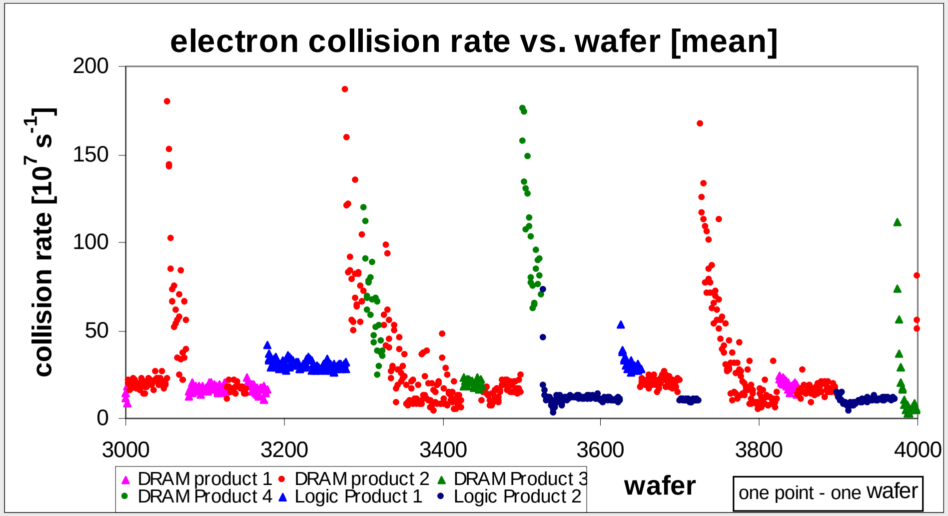
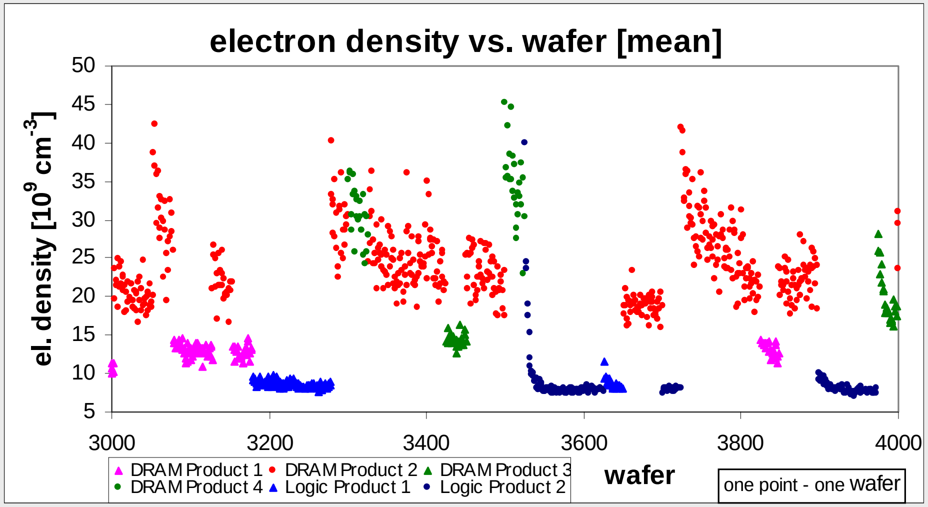
Results production monitoring - Over Etch



- Means of over etch steps (productive)
- Several selected memory and logic products shown
- Products distinguishable each by each ➔ influence of wafer and process

- Conditioning effects remarkable after every short clean
- Memory products cause significant chamber conditioning effects
- Logic products less conditioning



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Summary

- Plasma parameter measurement was used sccessfully to identify the main reason chamber performance difference – the top power coupling
  - Detection by electron density and electron collision rate
  - Proofed by Pareto analysis
- ➔ Recommendation for maintenance team:
  - Check whole RF input parts and connections and power coupling into the chamber
- Changes in pressure, powers, gas flows have nonlinear effects on electron density and electron collision rate
- Competing processes / reactions between chlorine and fluorine species
- Distinct between ohmic heating and stochastic heating shown by plasma parameters ➔ effects on etch rate and uniformity

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Summary (cont.)

- Drifting chamber conditions proven at both chambers by means of electron density and electron collision rate

- Production monitoring shows:
  - long time drift during wet clean cycle at main etch step
  - short time drift during short clean cycle at over etch step
  - memory products and their processes cause conditioning effects
  - products and groups of them distinguishable inside plasma parameters

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Questions and possibel aims

- Reason is narrowed down - confirmation by maintenance team necessary
- Detailed hardware reason not known
- Provide plasma parameter measurements including RF bias voltage (depending on tool supplier)
- Sequence inverted gas flow variation might confirm chamber chemistry influence on plasma parameter (for example: saturation behaviour of chamber wall)

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