Monitoring of process stability and chamber matching by plasma parameter measurement using High speed- SEERS

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Outline

- High speed SEERS features
- Strategy of plasma parameter application within AEC/APC
- High speed SEERS application examples
  - Process stability
  - Chamber matching
  - FDC - Fault detection and classification
- Summary

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High speed SEERS features

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Self Excited Electron Plasma Resonance Spectroscopy - How it does work

Measurement
RF Current
RF Peak Voltage

→

Calculation
FFT and
Model SEERS

→

Results in real time
Plasma Parameters

- RF up to 30th harmonics
- Passiv, no impact on process
- ➔ Easy current sensor qualification

- SEERS model limits:
  - One RF frequency higher than ion plasma frequency (4 … 6 MHz)
  - Pressure max. 300mTorr

- Electron Collision Rate [s^{-1}]
  - Mean electron collisions with gas molecules

  Electron Density [cm^{-3}]
  - = Plasma Density
- Bulk Power [mW/cm^2]
  - Power dissipated by electrons in plasma
- DC Bias Voltage [V]
  - it`s well known

Never stop thinking

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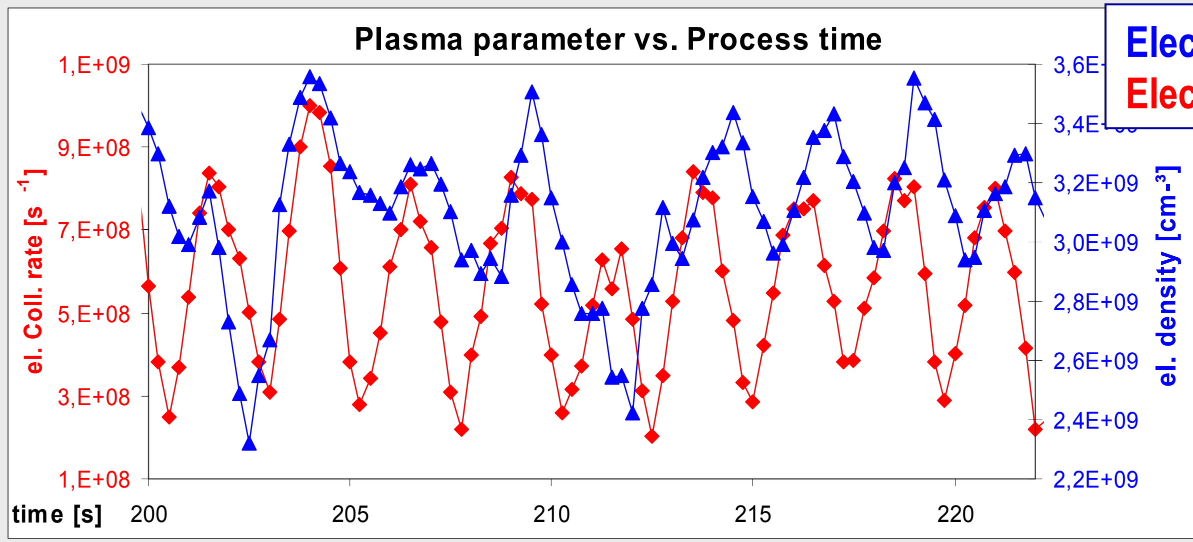
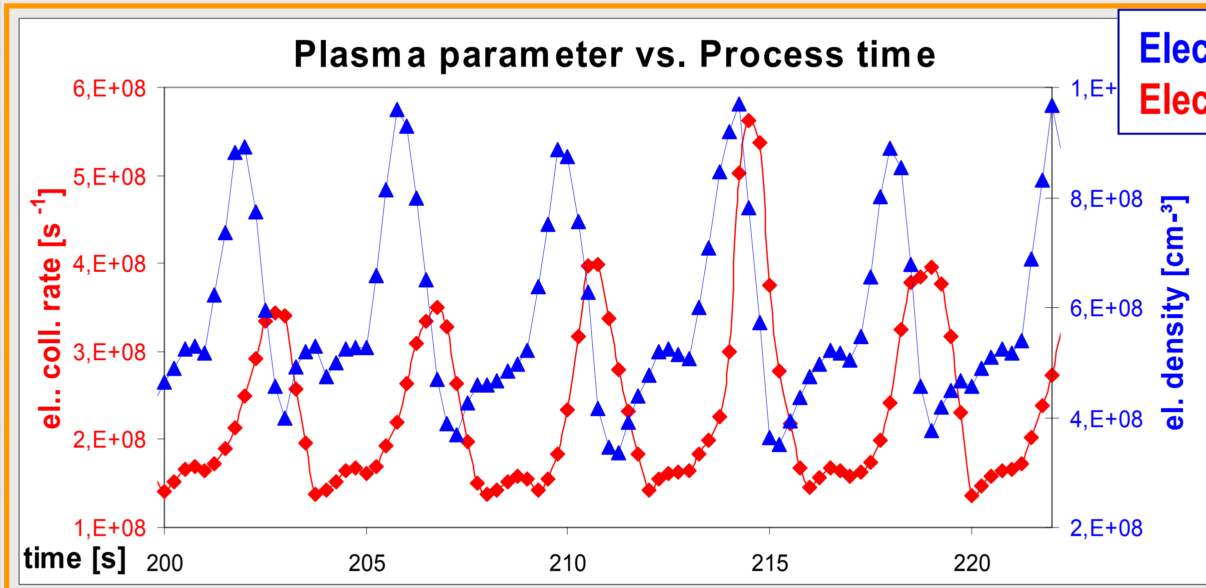
Dynamic effects in plasma: B- field rotation mode effect on process conditions - Results



Electron Density
Electron Collision Rate

B- field sine wave mode 0,5 Hz:



Electron Density
Electron Collision Rate

B- field square wave mode 0,25 Hz:

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High speed SEERS

Dynamic effects in plasma: B- field rotation mode effect on process conditions - Discussion

- High speed SEERS modus: up to 15 measurements per second
- Electron collision rate and electron density show B- field mode (square or sinus) impact on process conditions.
  - Oscillation indicate electrically asymmetric chamber geometry
  - Electron density (plasma density) with sine wave B- field mode recipe indicates plasma instabilities
  - Phase shift between electron density (= plasma density) and electron collision rate (see B-field square wave mode 0,25Hz)
  - Hypothesis of phase shift root cause: Retardation between plasma excitation (electron density) and resulting gas composition

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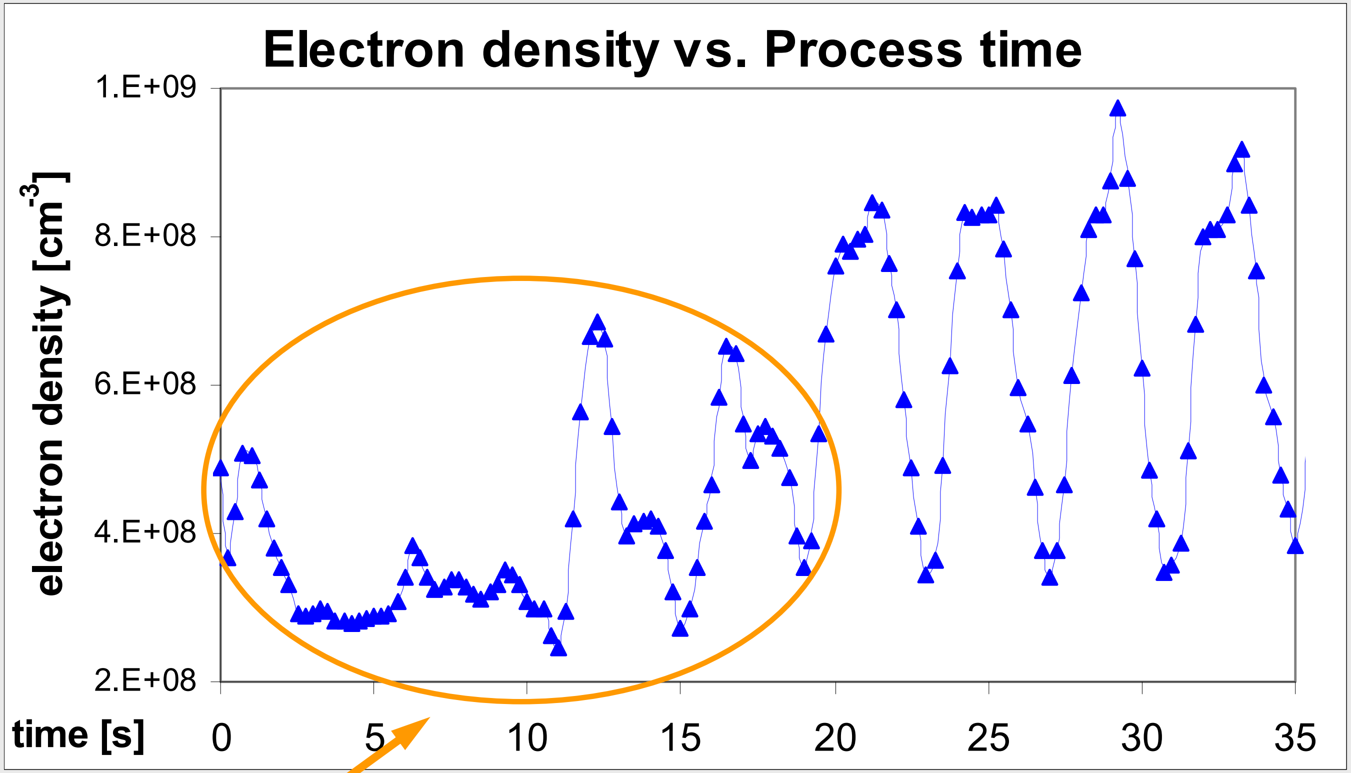
Dynamic effects in plasma: Plasma stabilisation at process start



- Process stability reached after about 20 s
- Plasma density oscillation caused by rotating B- field

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Strategy of plasma parameter application within AEC/APC

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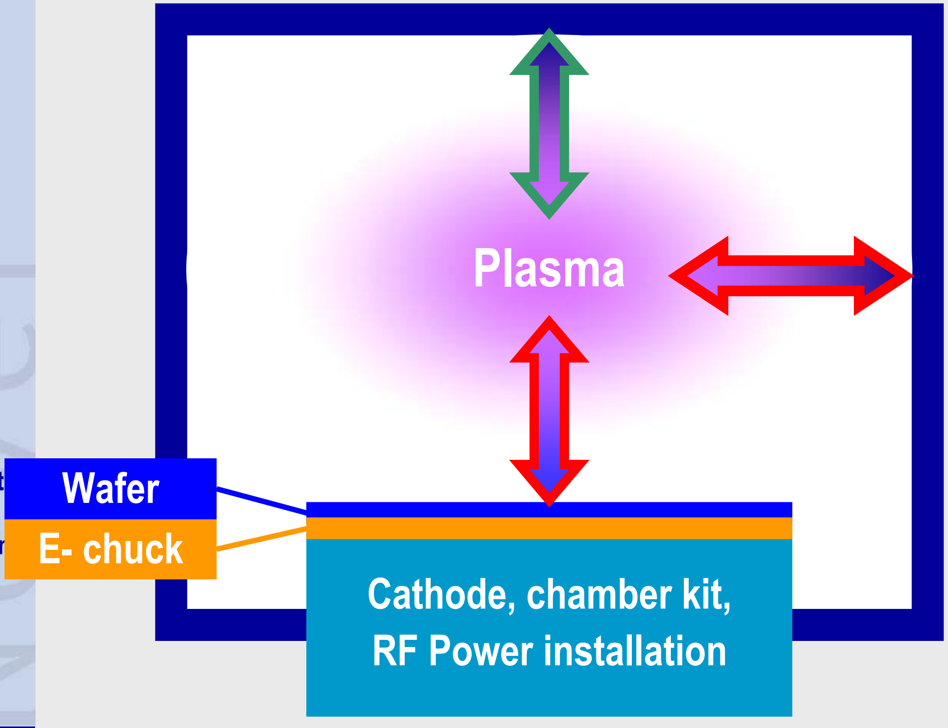
The Plasma is your Tool

The chamber is the tool box only.
The plasma in the chamber – that´s your Tool really.



- Some parameters can be measured, for example:
  - MFC gas flow, pressure …
- Other parameters cannot be measured, for example:
  - Gas adsorption and desorption at chamber wall = conditioning
- Processes on wafer surface are difficult to monitor.

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Plasma parameters = key indicators of process conditions

How **electron collision rate** ν_e and **electron density** n_e indicate process conditions in plasma (simplified equations):

$$\nu_e = \frac{e^2}{\varepsilon_0^2}\frac{n_e^2}{B^2}\frac{p_{gas}}{k_B T_{gas}}\left(\frac{p_1}{p} v_e \sigma_1(v_e^{-1}) + \ldots\right)$$

$$n_e \sim B_0^2 \, U_{peak} \, f(p_{Gas})$$

RF power input	Gas Pressure
B- Field	Gas Temperature
	Gas Composition

- Plasma parameters summarise process impacts, which are:
  - known and measured easily
  - known and difficult to measure
  - unknown and cannot be measured at all
- **Plasma parameters = key indicators of process conditions**

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Application Strategy

Plasma parameter application as a process health indicator in AEC/APC

Plasma parameters give you direct information about the plasma - your Tool.

- Detection of statistical significant process drift:
  - Caused by measurable effects with very high sensitivity
  - Caused by indirectly measurable effects
  - Caused by recipe parameters, chamber, wafer
- Data compression:
  - By the measured parameter, „by Physics“ itself

Plasma parameters are real time process health indicators.

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High speed SEERS applications within AEC/APC

Process stability
Chamber matching
FDC

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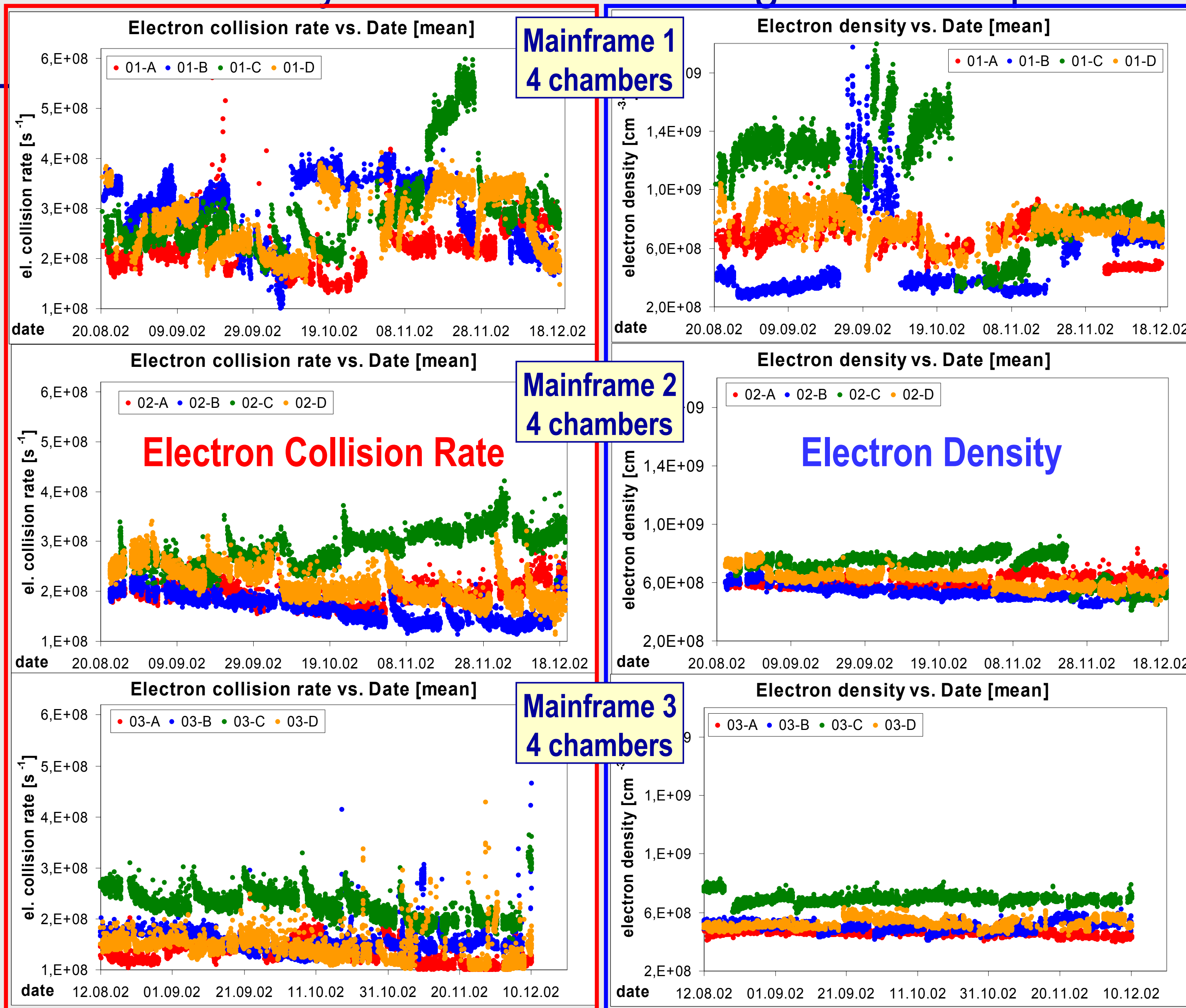
Application Examples

Process stability & chamber matching of an etch process



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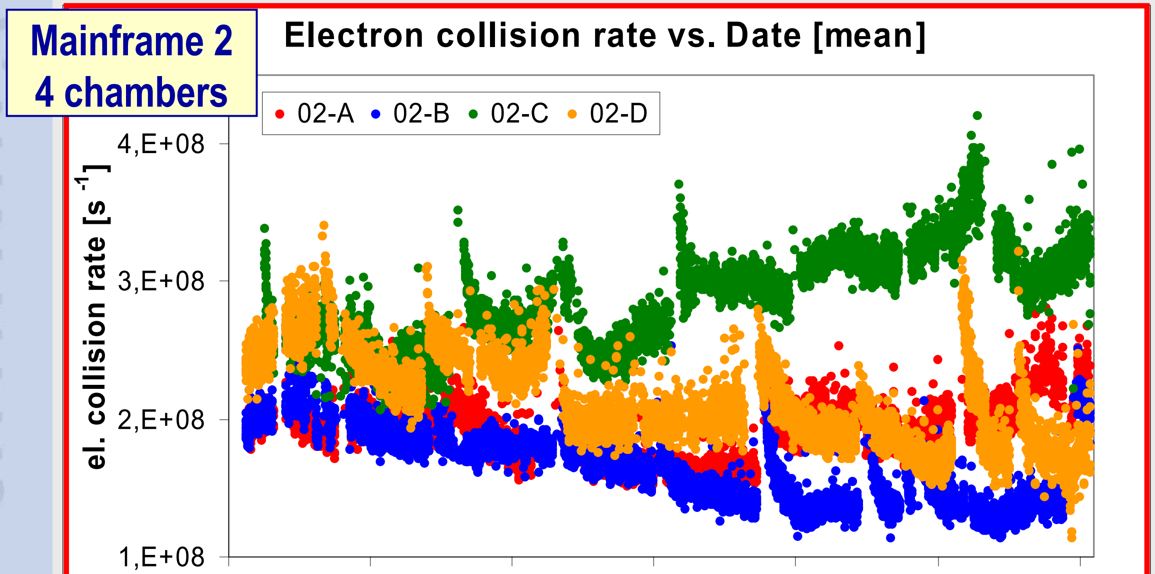
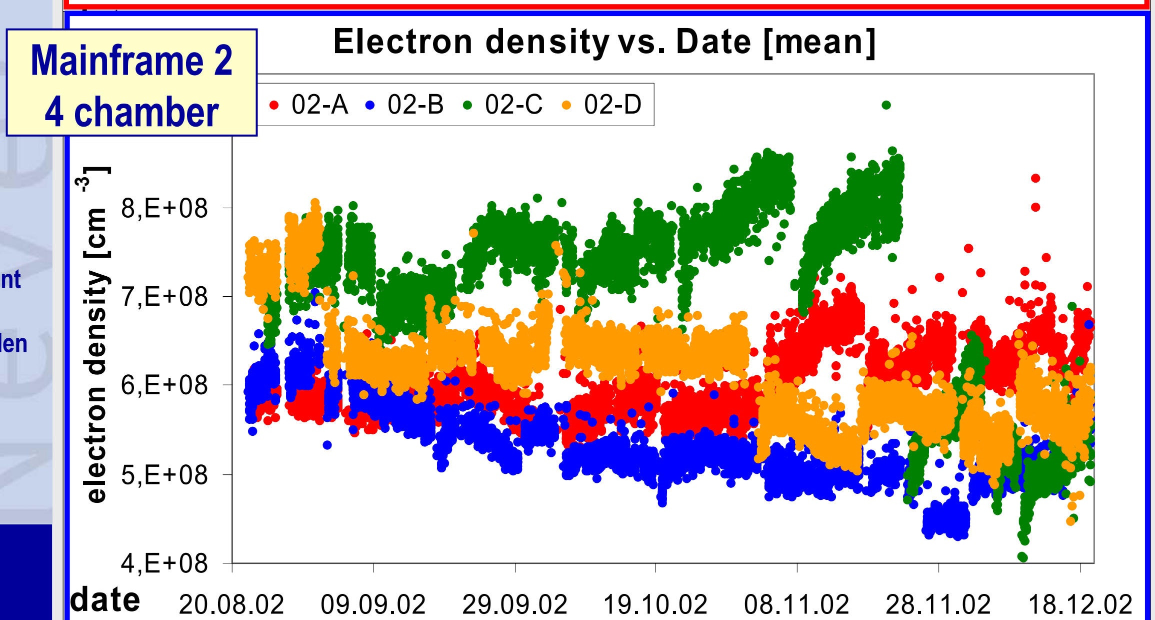
Process stability and chamber matching of mainframe 2





- Superimposition of long term drift and short term process condition drift in plasma
- Wet clean impact on process conditions is clearly seen by both parameters

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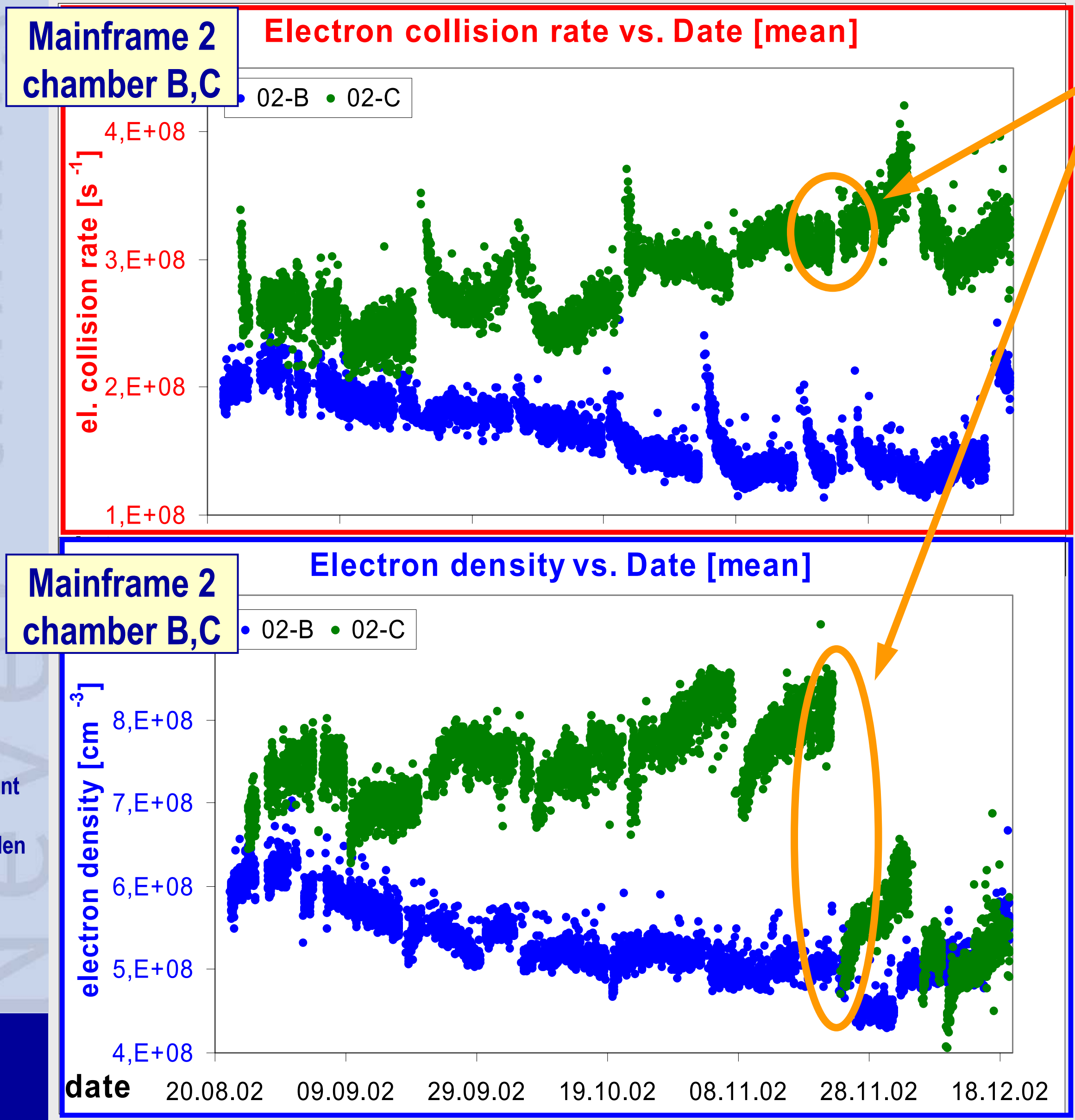
Process stability and chamber matching of mainframe 2, chamber B and C



- Electron collision rate and electron density indicate different effects on process conditions (see page 11)

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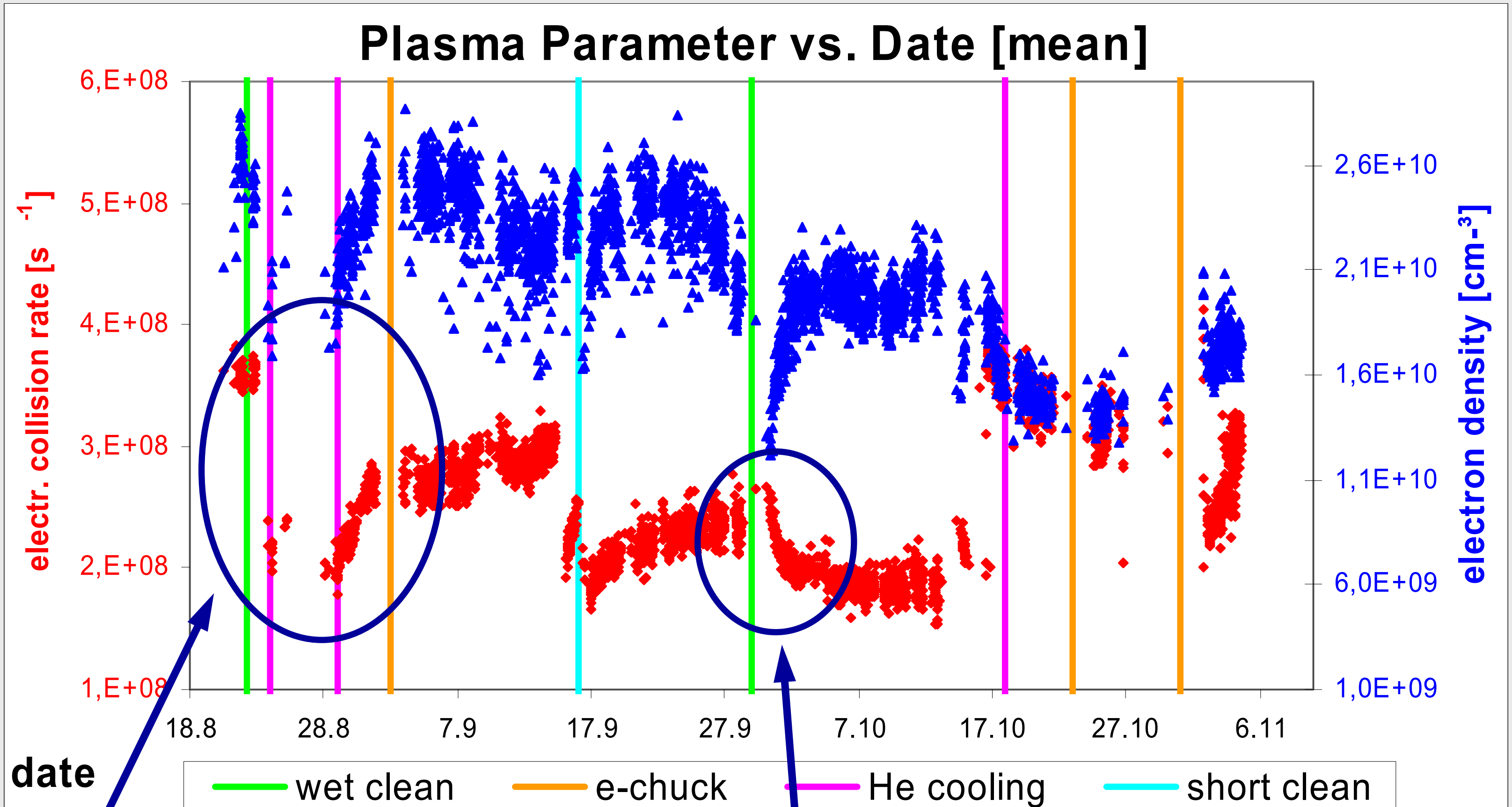
Wet clean monitoring with plasma parameters of an etch chamber



Wet clean abnormal

Wet clean normal

- Electron collision rate shows normal and abnormal wet clean clearly

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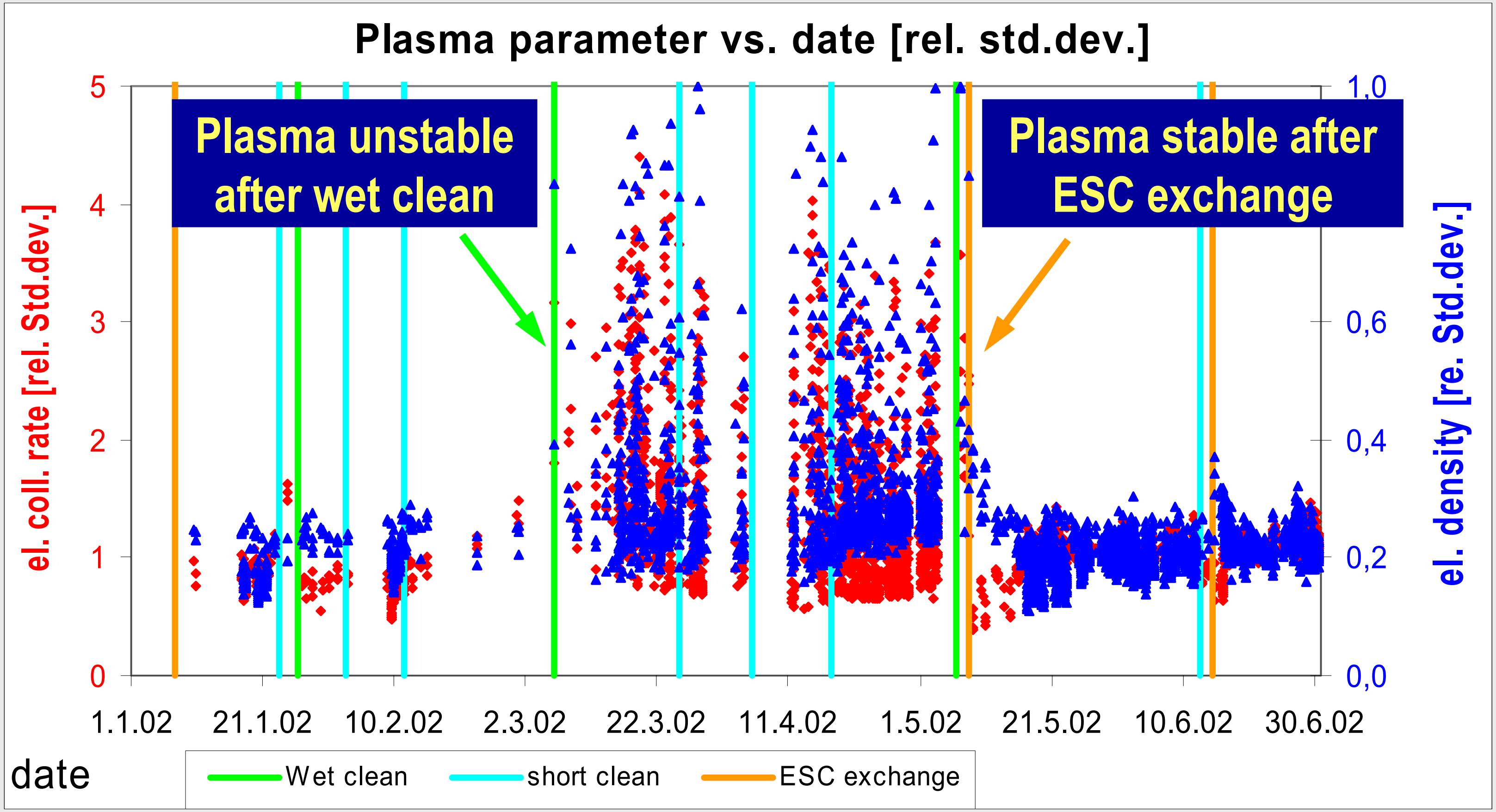
Stability and FDC

FDC: E- chuck fault detection in an etch chamber



- Electron collision rate and electron density show e-chuck faults clearly

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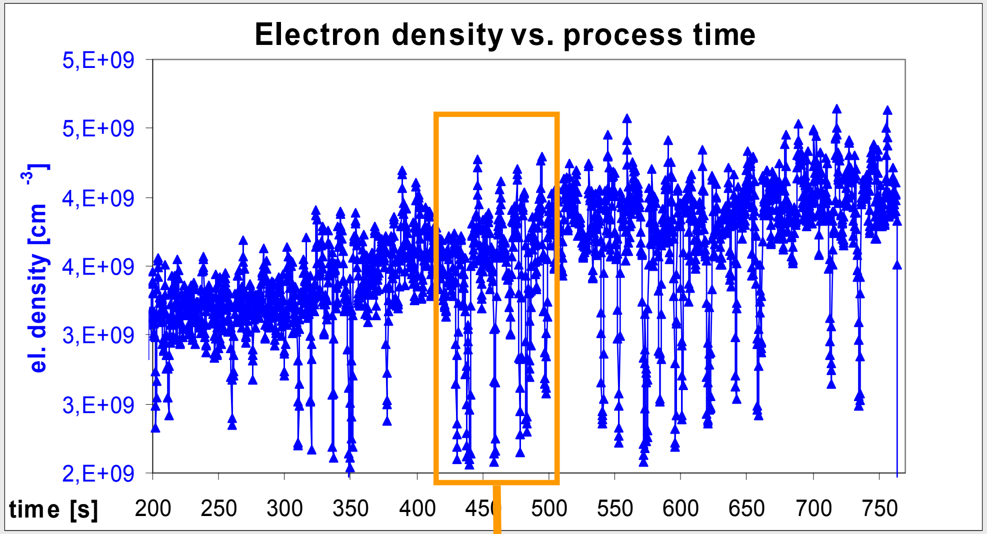
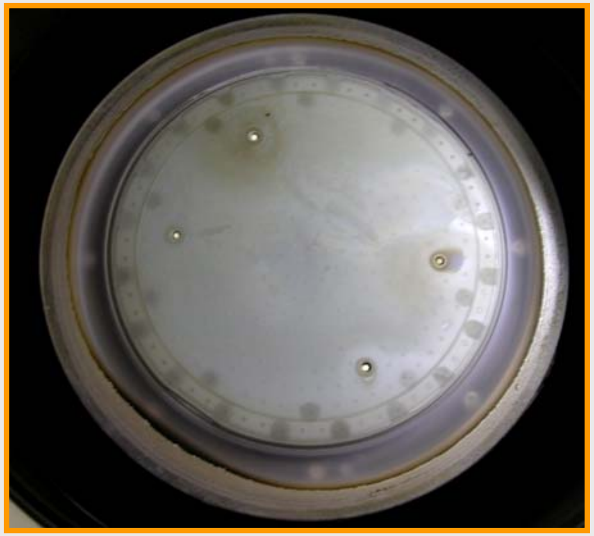
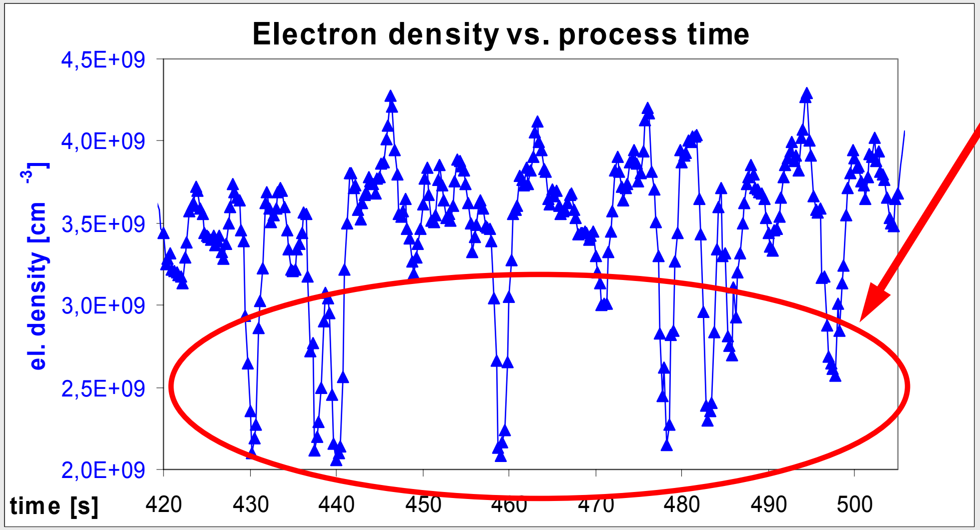
FDC: Detection of unstable plasma and arcing in an etch chamber with rotating B- field







Detection of **unstable plasma and arcing** by electron density (= plasma density) measurement

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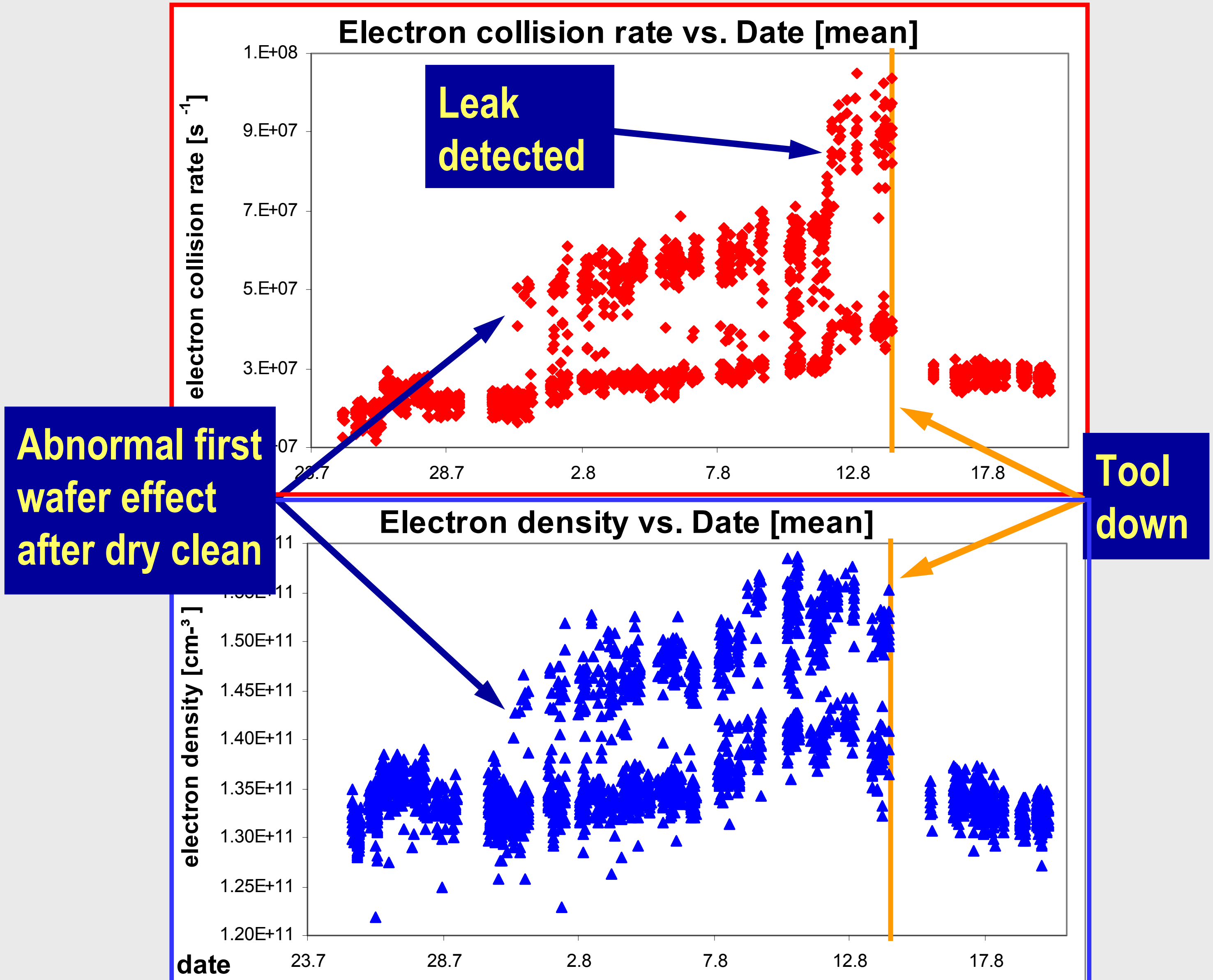
FDC: Conditioning monitoring and leak detection of CVD process



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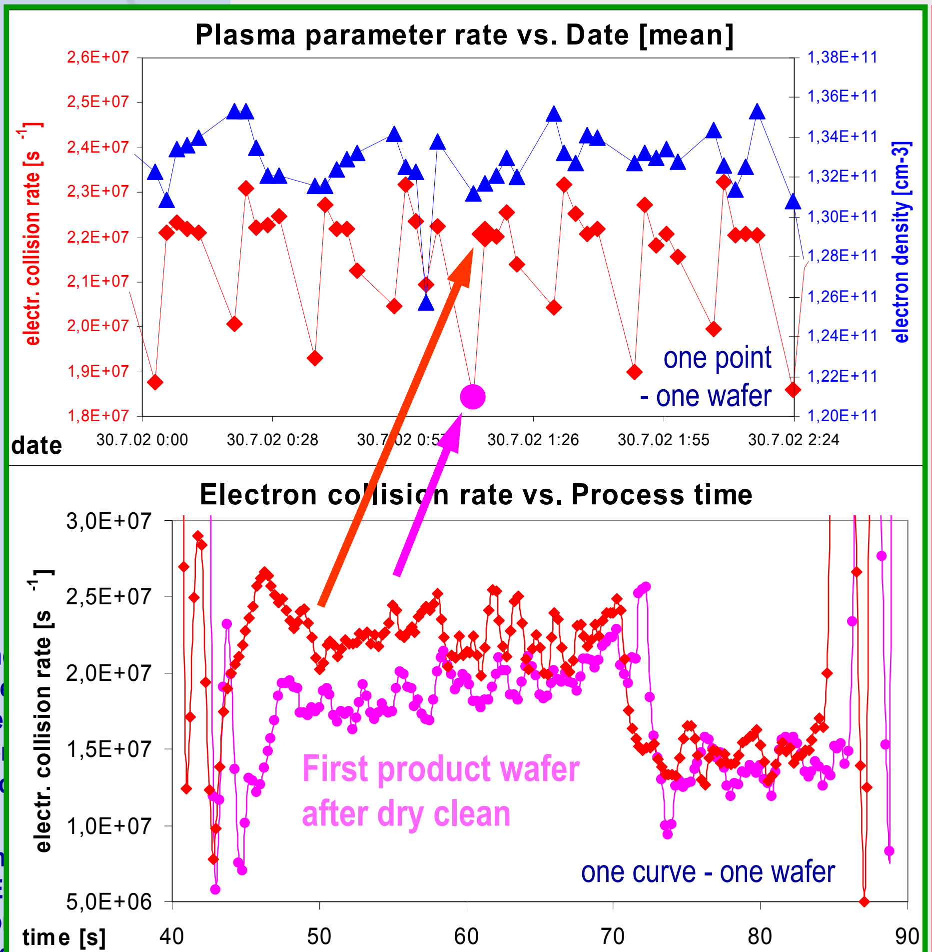
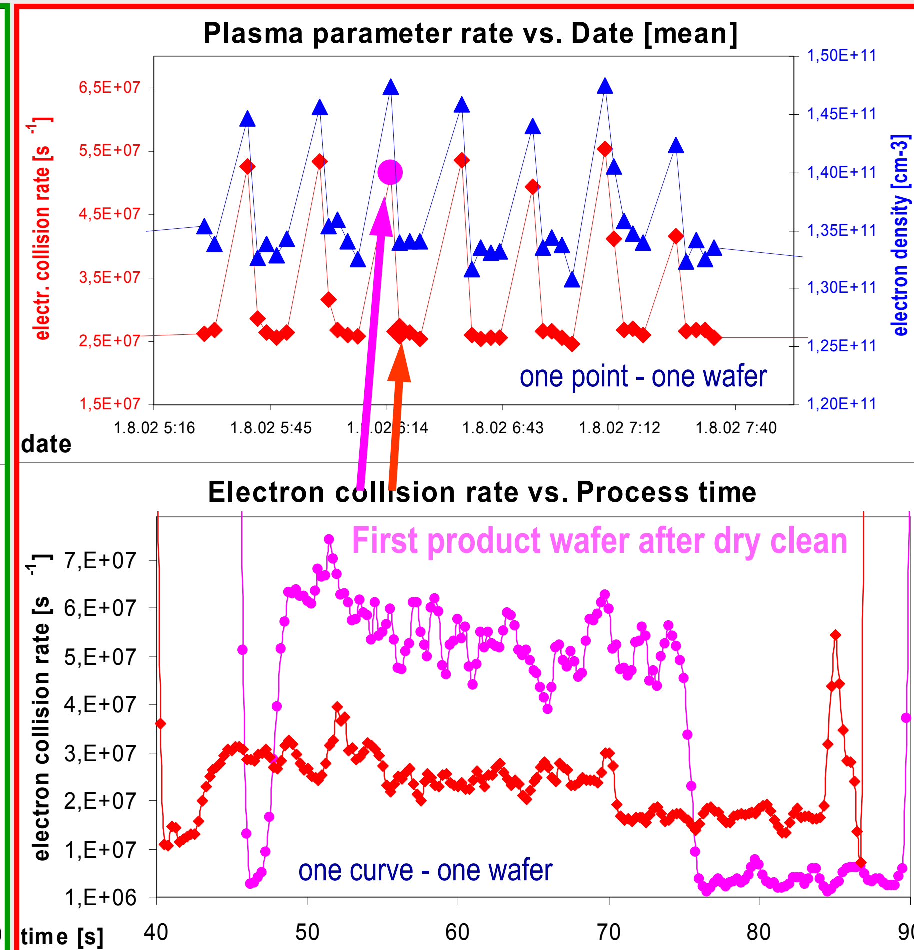
Conditioning monitoring – First wafer effect after dry clean of CVD process

is normal ← First wafer effect → **is abnormal**





Stability and FDC

FDC:
First wafer effect and leak detection - discussion

- Conditioning:
  - Dry clean every 5th wafer ➔ Impact on chamber wall surface
  - Chamber re- conditioning takes about 20 .. 25s on following product wafer
  - Conditioning effects are not detected by tool parameters
  - ➔ Electron collision rate = „Conditioning indicator“
- Leak detection:
  - Leak was detected by increase of chamber pressure and electron collision rate
  - But electron collision rate rise was about ten times higher than pressure increase !
  - ➔ Electron collision rate detects very small leaks, which cannot be found using tool parameters, e.g. pressure

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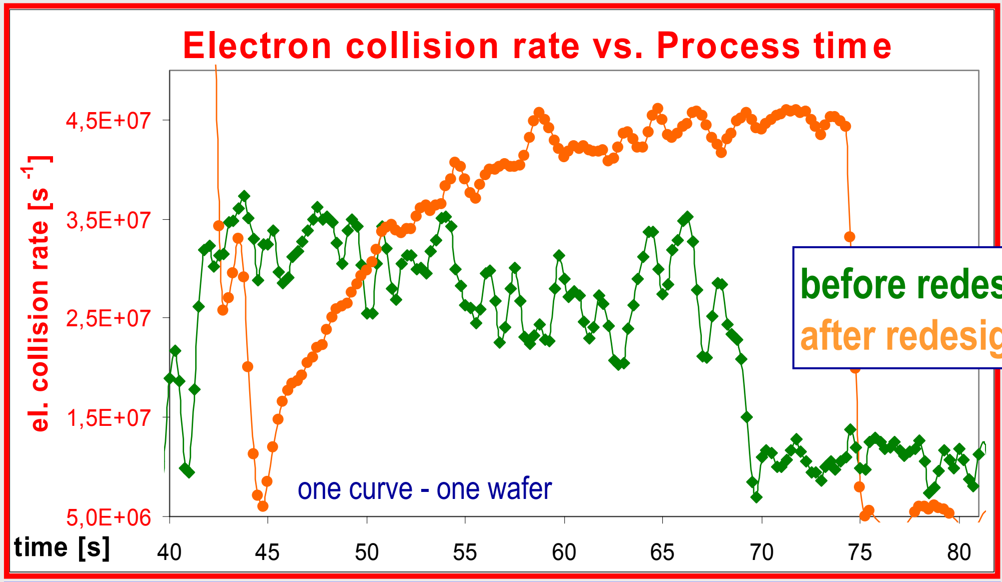
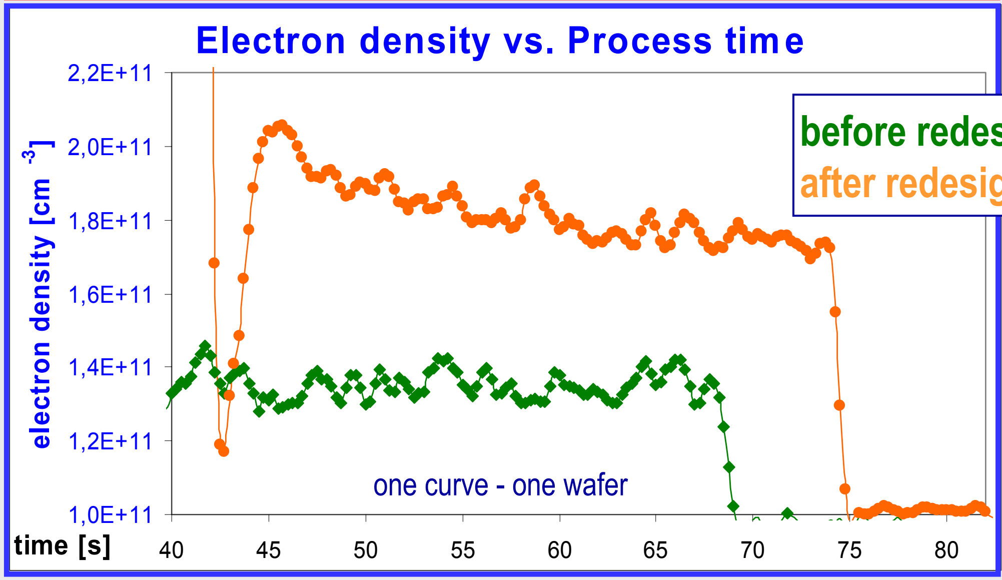
Chamber matching: CVD chamber redesign effect on process stability





- Same recipe after chamber redesign ➔
- Electron collision rate less noisy, but significant drift (gas composition)
- Increase of electron density indicates increased plasma density (effective power input)

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Summary

- Plasma parameters, like electron collision rate and electron density, characterise process conditions in plasma directly.
- High speed SEERS enables real time plasma parameter measurement with fast response time ➔ Short dynamic processes in plasma can be monitored.
- Applications of High speed SEERS were demonstrated with etch and CVD processes:
  - Process stability monitoring
  - Chamber matching
  - FDC
- Plasma parameters can be used as real time process health indicators.