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Application of **S**elf **E**xcited **E**lectron Plasma **R**esonance **S**pectroscopy for Advanced Process Control of plasma etch processes

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Outline

- **A**dvanced **P**rocess **C**ontrol in Semiconductor Technology today
- **S**elf **E**xcited **E**lectron Plasma **R**esonance **S**pectroscopy
- SEERS application examples

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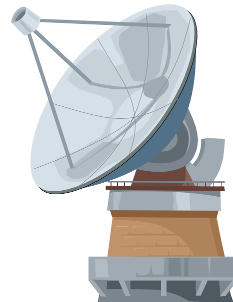
Advanced Process Control in semiconductor technology

- Why do we need Advanced Process Control at semiconductor technology today ?
  - Economical reason → 300mm wafers
  - Technological reason → Critical dimensions < 100nm
  - Tool limits → Process stability, Chamber matching
- Critical: Lithography, Plasma Processing
  - New in-situ measurement techniques needed
  - **S**elf **E**xcited **E**lectron Plasma **R**esonance **S**pectroscopy is a new „electrical“ in-situ plasma measurement method



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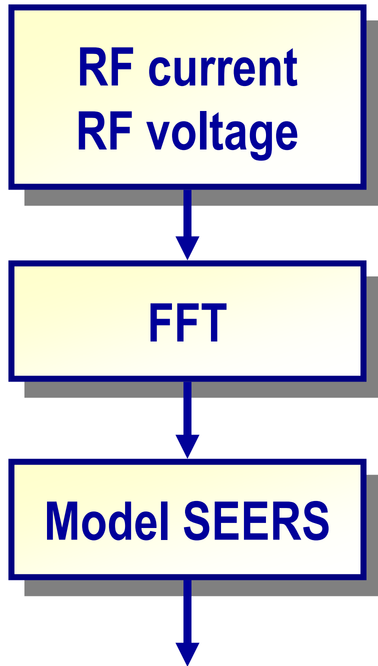
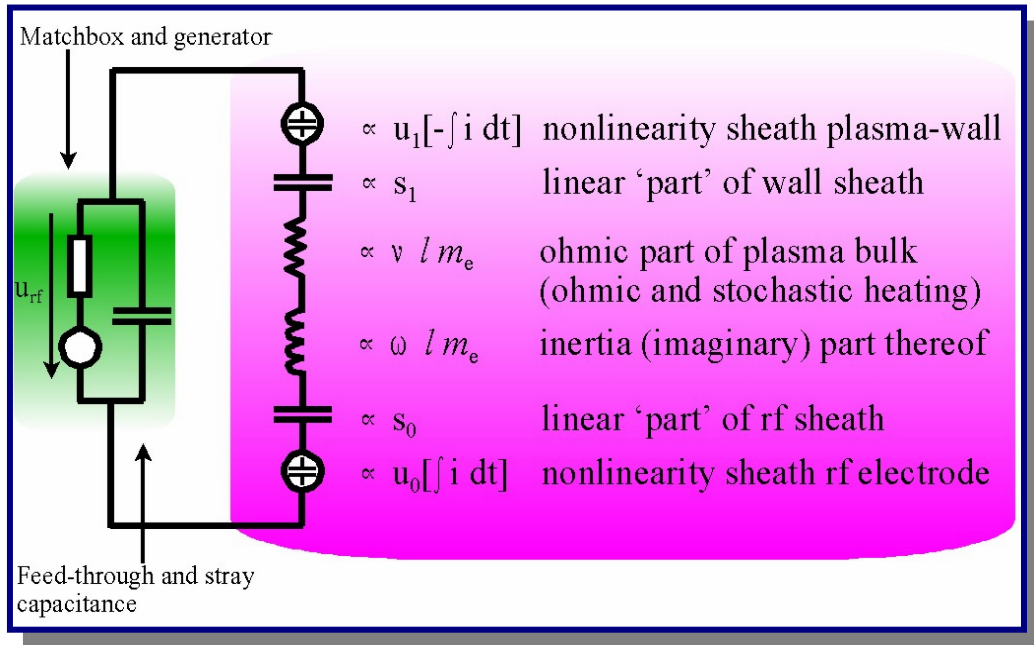
Principle of Self Excited Electron Plasma Resonance Spectroscopy



Electron collision rate
Electron density
Bulk power
DC bias voltage



- Plasma model focussed on electron interactions
- Border conditions:
  - One RF frequency > 4 … 6 MHz
  - Pressure < 300mTorr

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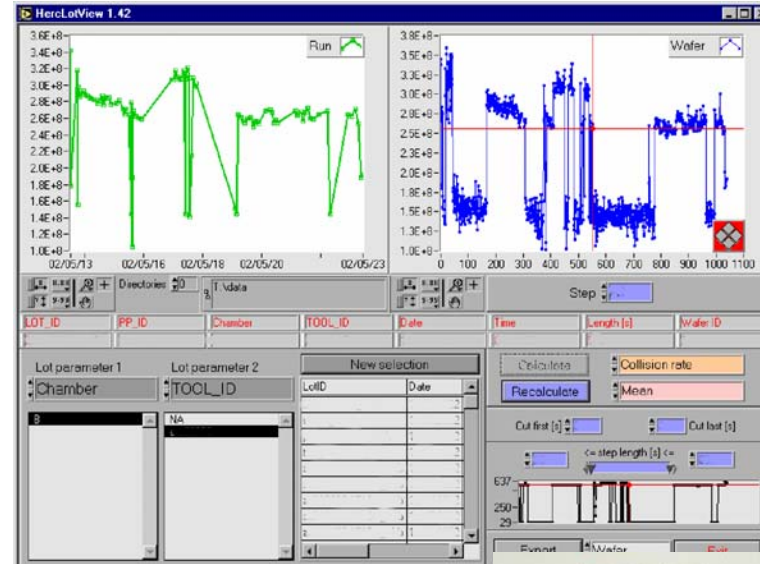
Hercules – the „plasma oscilloscope“ using SEERS

- Absolute mean physical parameters
  - Electron Collision Rate [s^{-1}]
  - Electron Density [cm^{-3}]
  - Bulk Power [mW/cm^2]
  - DC Bias Voltage [V]



- Passive method:
  - No impact on process conditions
  - Measurement directly at product wafer processing

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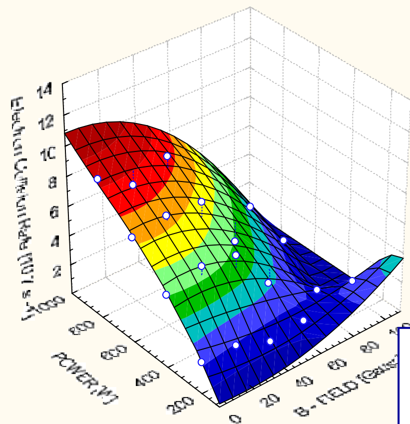
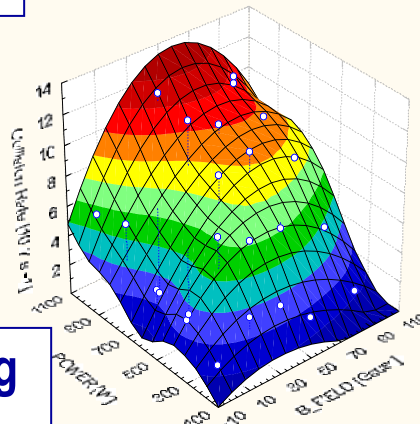
Plasma is a complex and non-linear tool at semiconductor technology



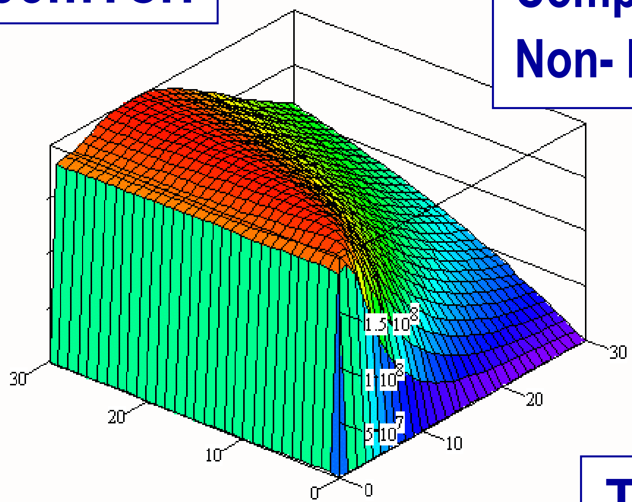
Experiment

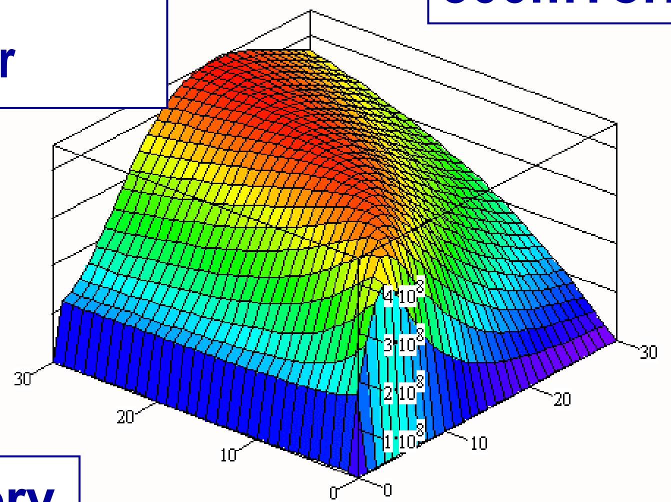


100mTorr

300mTorr

- Many interacting phenomena
- Complex
- Non- linear





Theory

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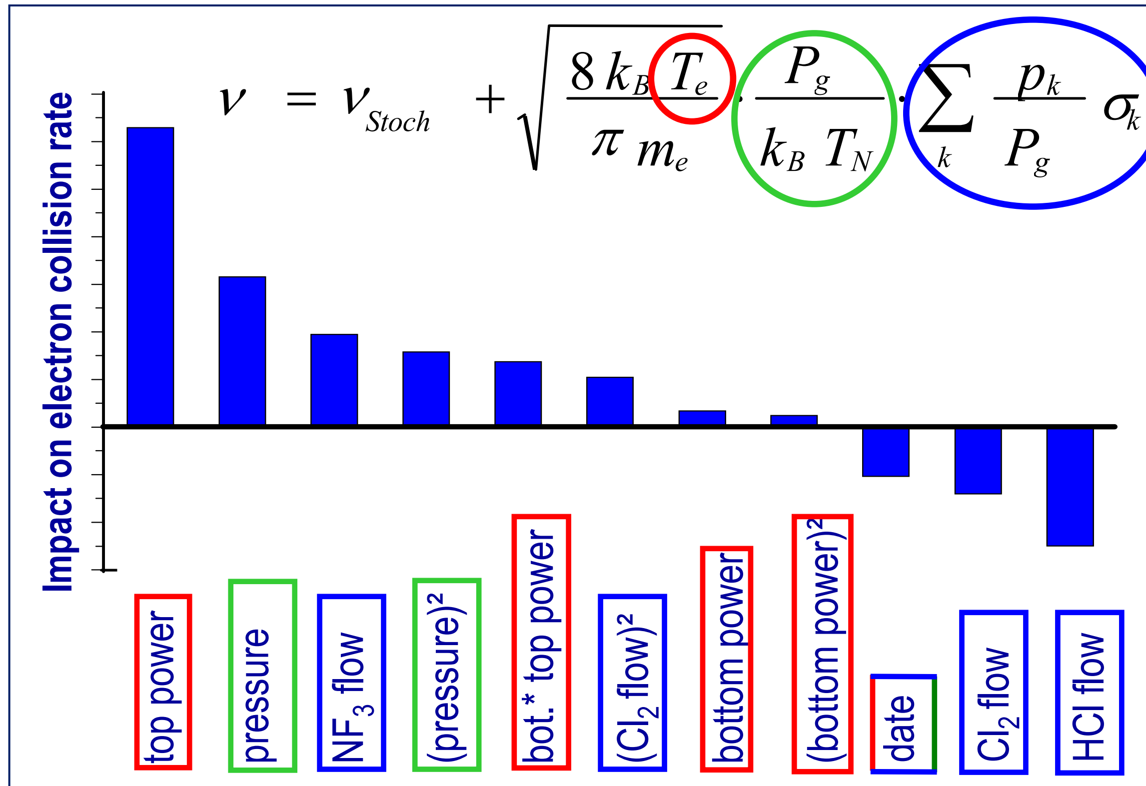
Electron Collision Rate – example of a complex non-linear plasma parameter



- Real power dissipation in the chamber
- Real particle density in plasma
- Real gas mixture in chamber

- Electron Collision Rate depends on:
  - Easy measurable impacts on process and
  - Difficult or even not measurable impacts on process

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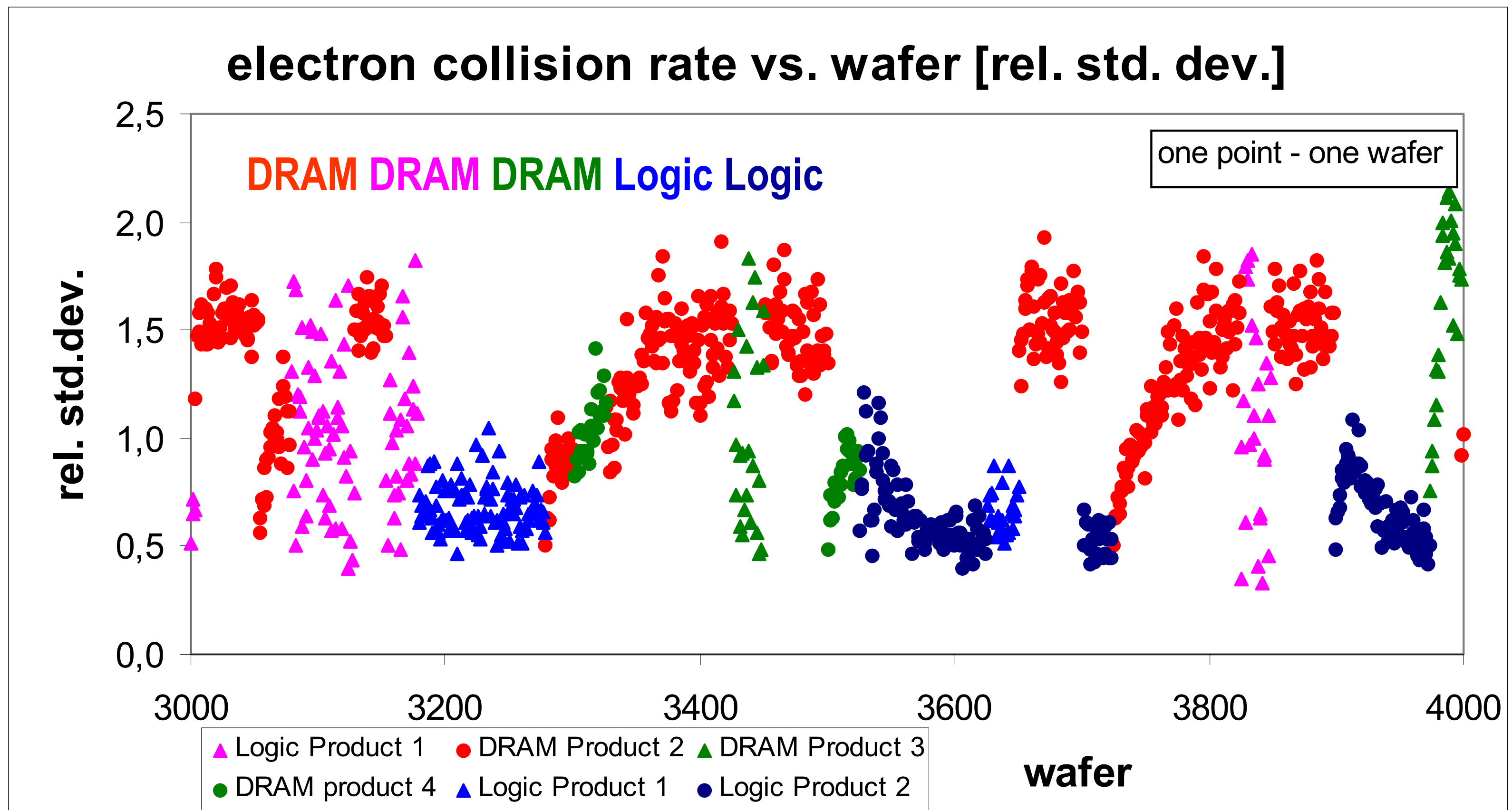
Process stability of product mix at Gate Contact etch in LAM TCP



- Electron Collision Rate indicates impact of DRAM and Logic products on chamber conditioning

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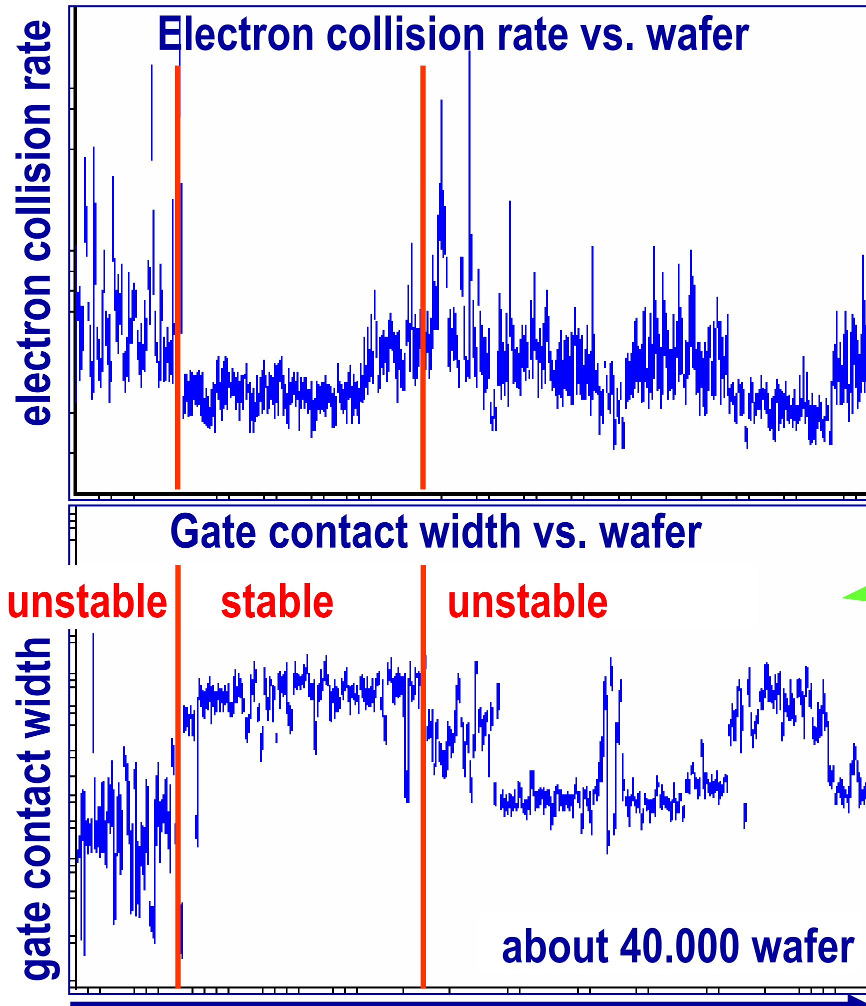
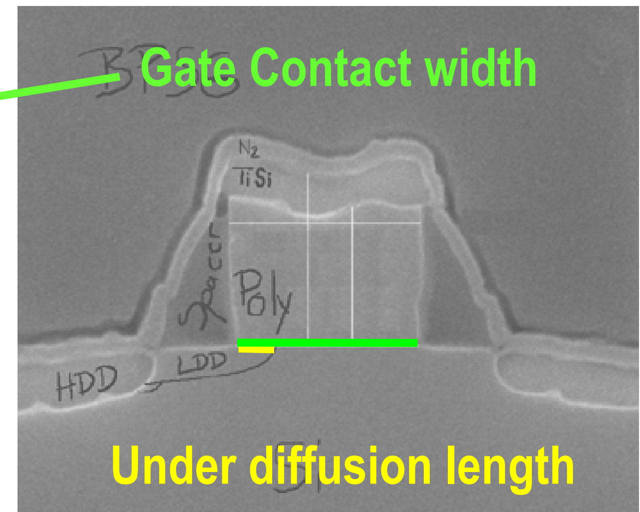
Process conditions impact on Logic product at GC etch in LAM TCP



- Electrical parameters of Logic product depend on chamber conditions at Gate Contact etch



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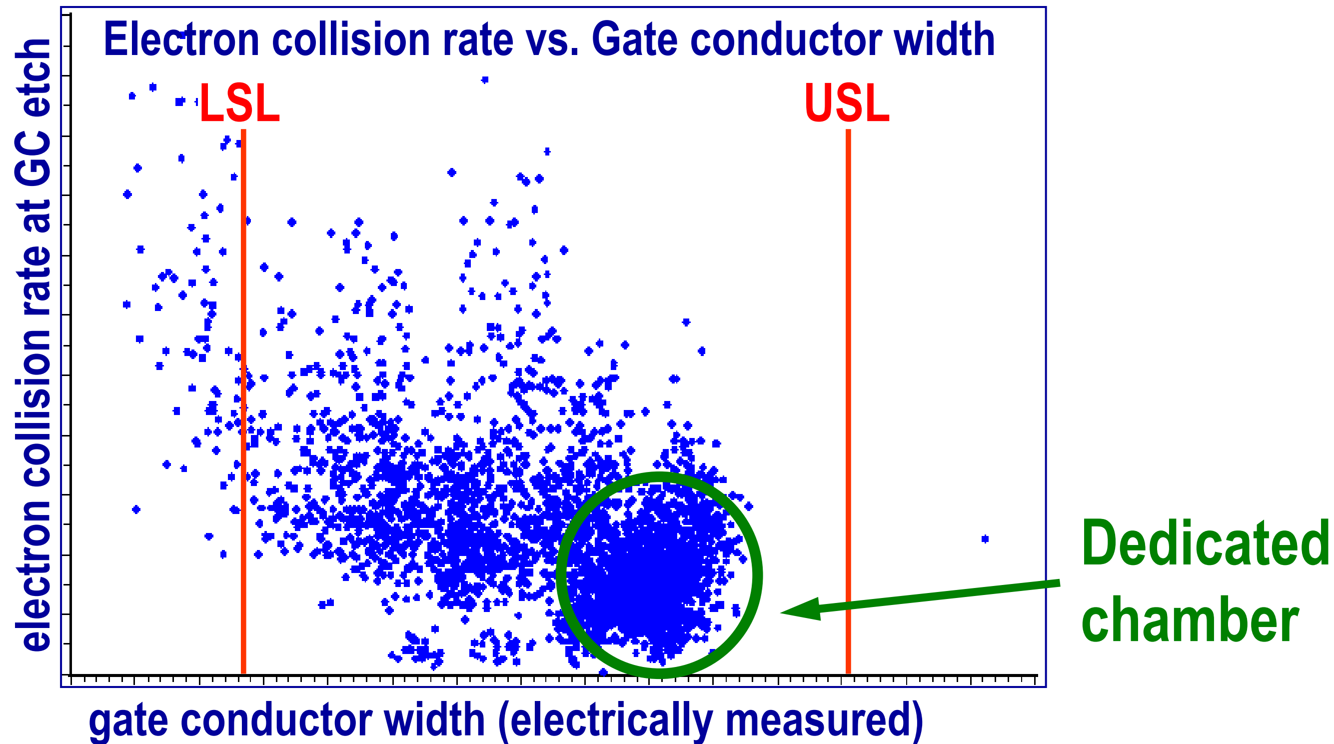
Correlation between Electron Collision Rate and Gate Contact width



- Electron Collision Rate indicates GC etch impact on Gate Contact width of Logic product in real time

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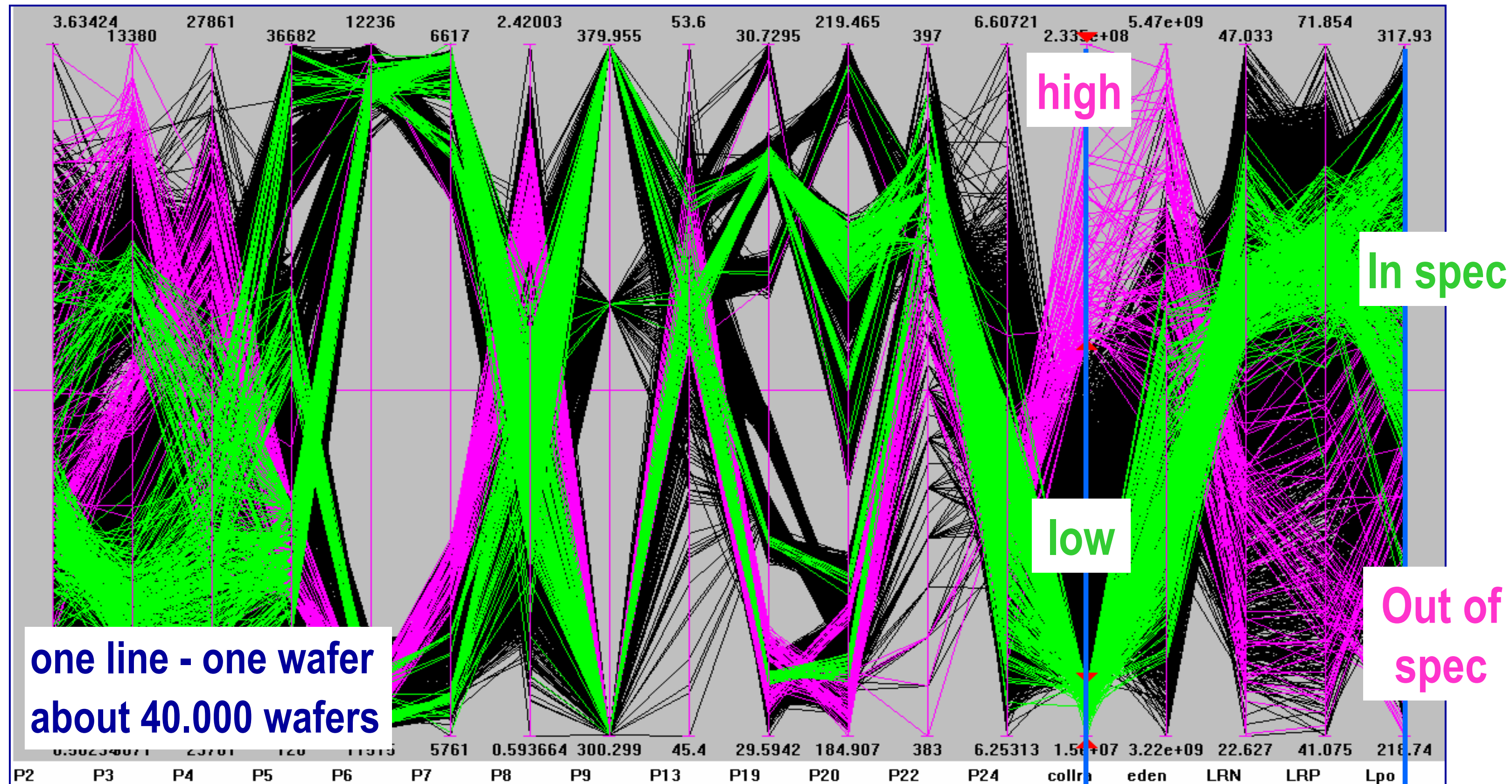
Correlation visualized in parallel coordinate plot



Electron collision rate

Electrical product parameter

- Electron collision rate shows best correlation to product parameter

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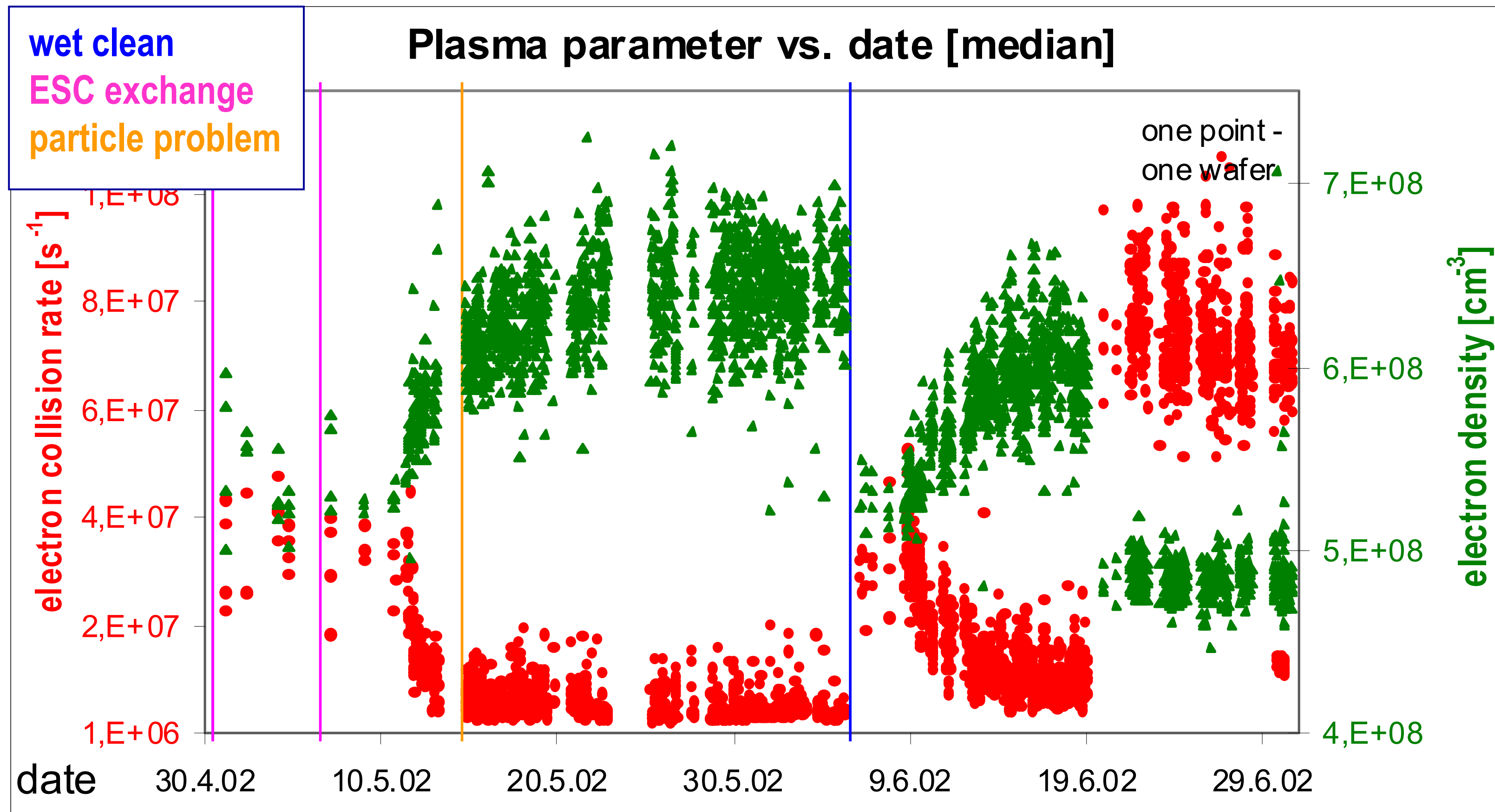
Wet clean impact on process stability at 300mm Si etch chamber



- Electron collision rate and electron density indicate wet clean impact on process stability

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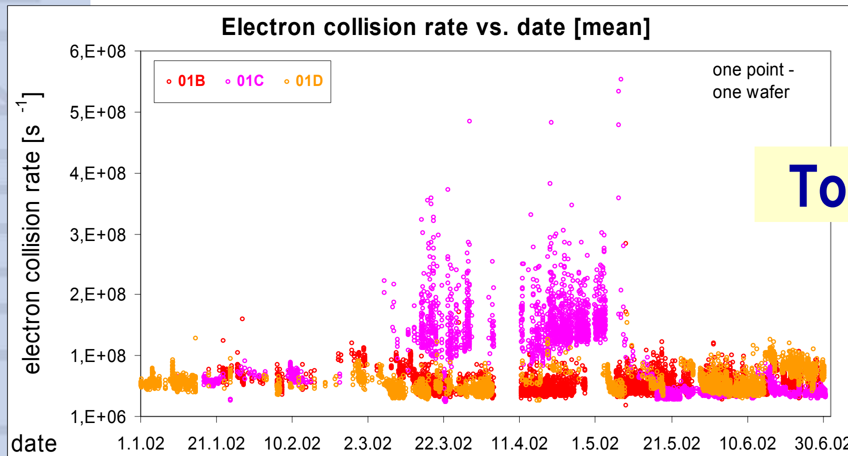
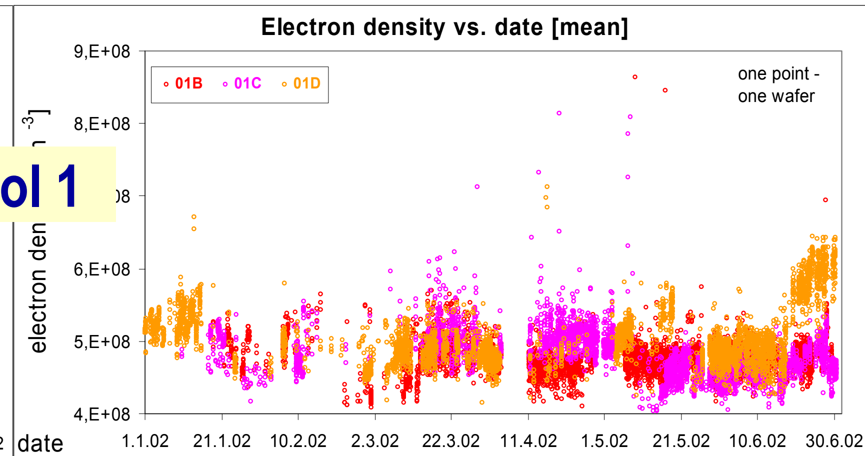
Process stability and chamber matching at 300mm Si etch chambers

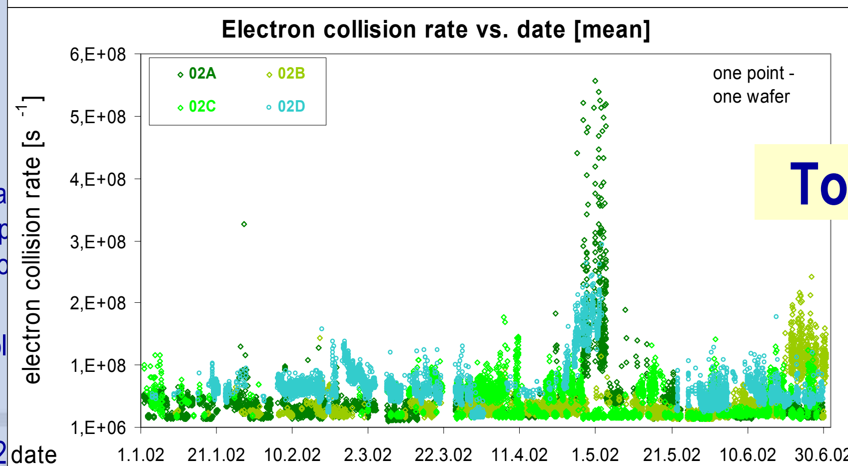
Electron collision rate

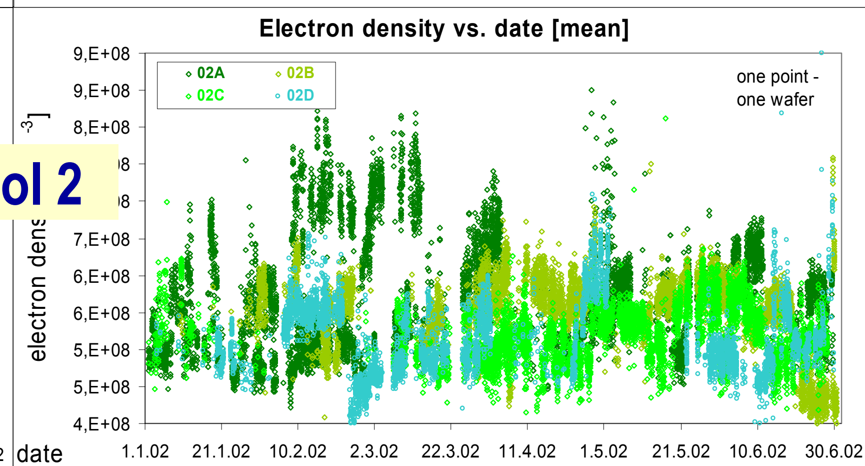
Electron density





Tool 1





Tool 2

- Process monitoring at 7 chambers for 6 months

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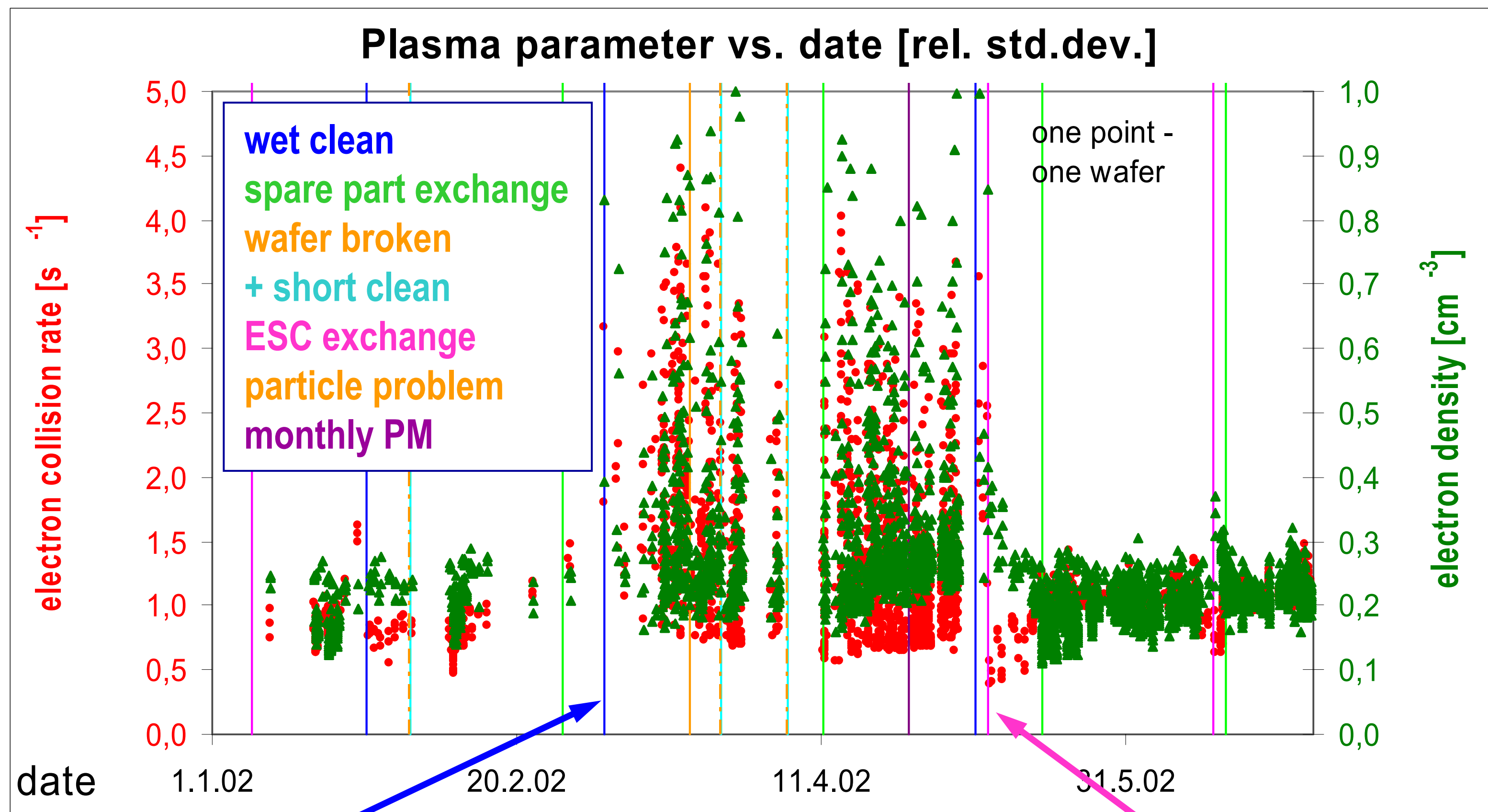
Fault detection at 300mm Si etch chambers



Unstable process caused by wet clean

Process stable after ESC exchange

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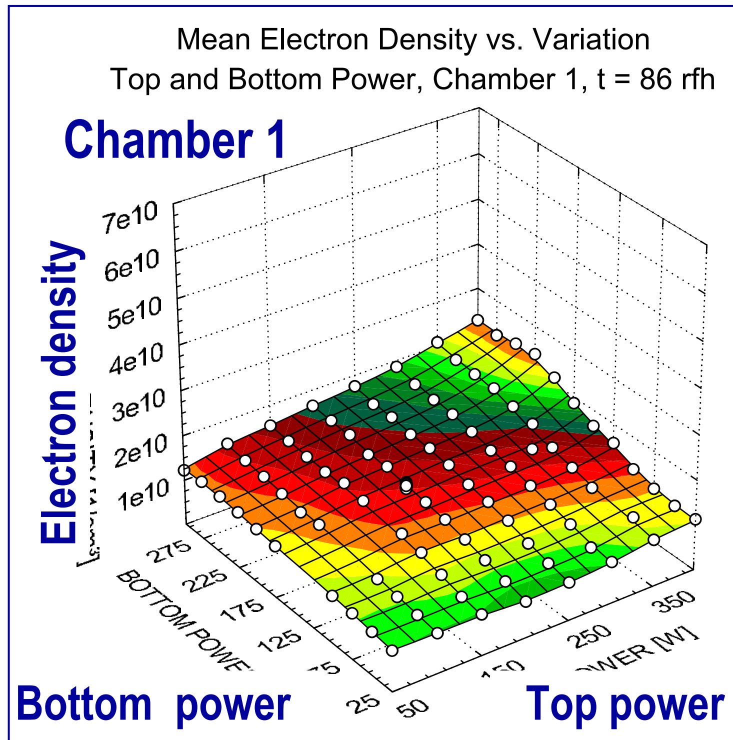
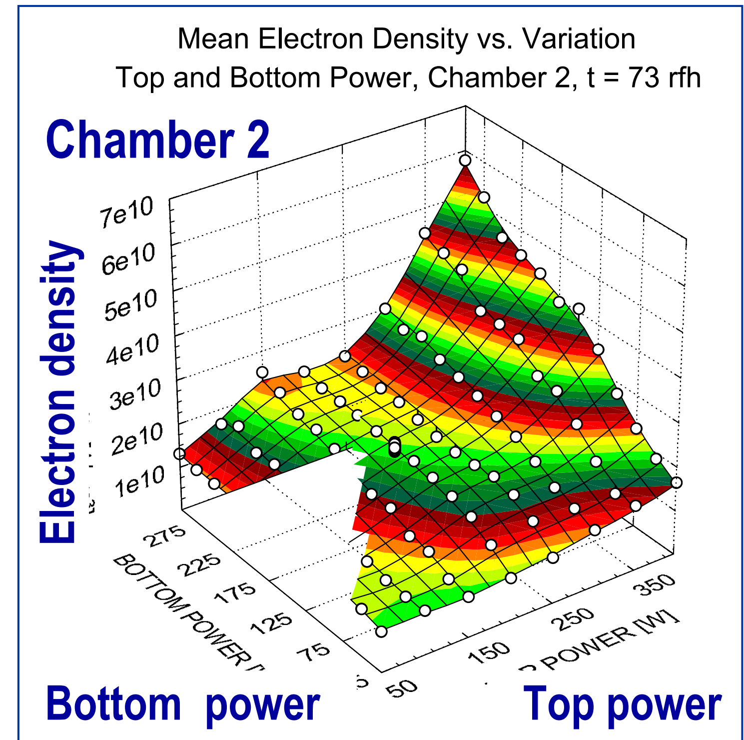
Chamber matching at LAM TCP by Electron Density measurement





- "Identical" chambers and recipe ➔ different result
- Electron Density detects difference in power dissipation, caused by TCP top power coupling

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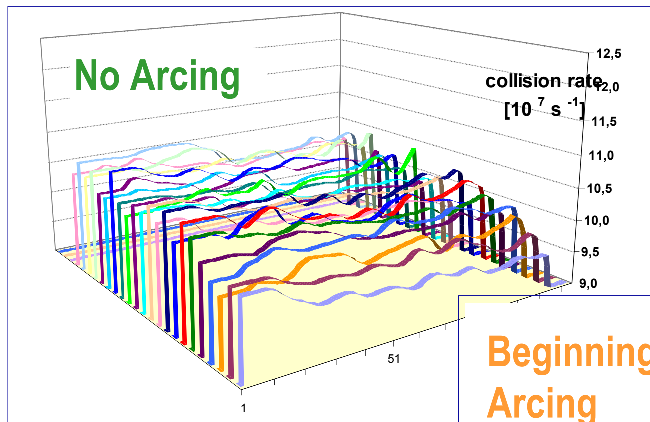
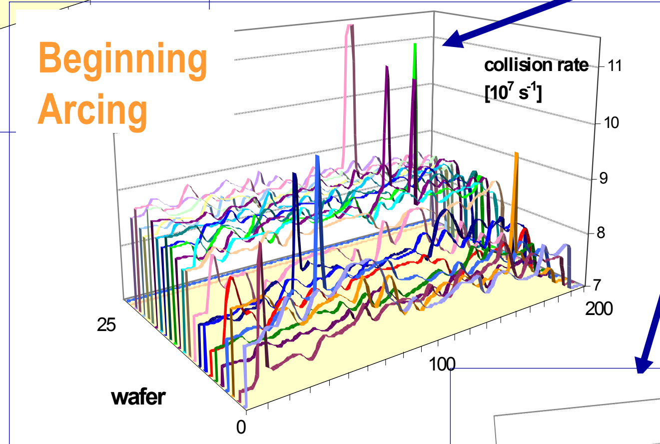
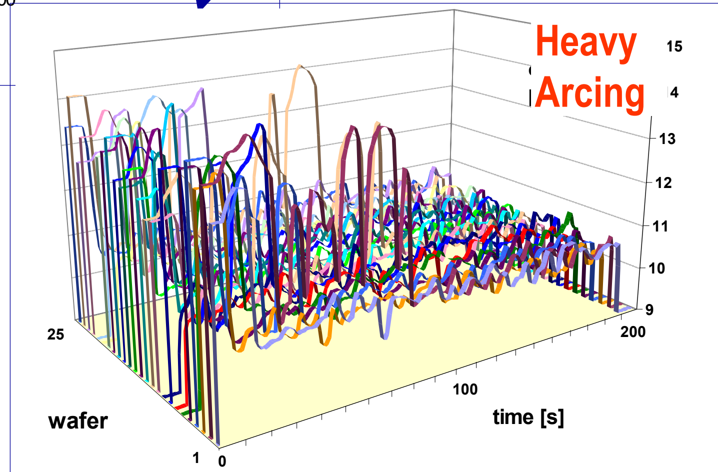
Fault Detection: Arcing inside He feedthrough of AMAT MxP+







- Arcing detected by measurement of electron collision rate

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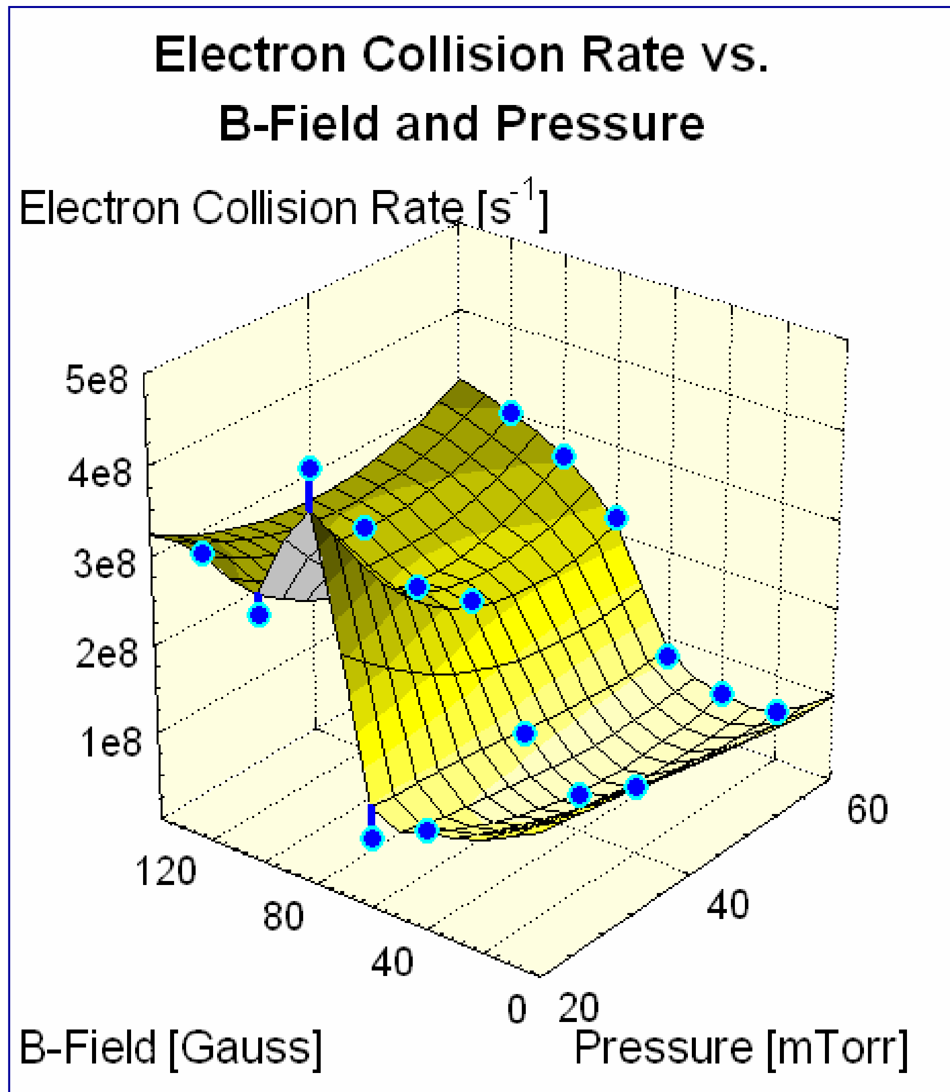
Process development: Monitoring of process window linearity



- Electron collision rate shows non-linearity inside process window
- Reduced efforts at process development

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Summary

- Advanced Process Control using new in-situ monitoring methods is needed to achieve high proces stability.
- Self Excited Electron Plasma Resonance Spectroscopy is a new, very promising in-situ plasma monitoring method.
- Applications as **real- time indicator** of process conditions in high volume production of DRAM and Logic products were shown.

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