Introduction

Application of the Plasma Monitoring System HERCULES for real time plasma etch control

A. Steinbach	**Infineon Technologies Dresden**
S. Bernhard	**Infineon Technologies Dresden**
M. Sussiek	**Technische Universität Hamburg - Harburg**
C. Steuer	**Technische Universität Dresden**

Infineon Technologies Dresden

. Steinbach
. Bernhard
. Sussiek
. Steuer

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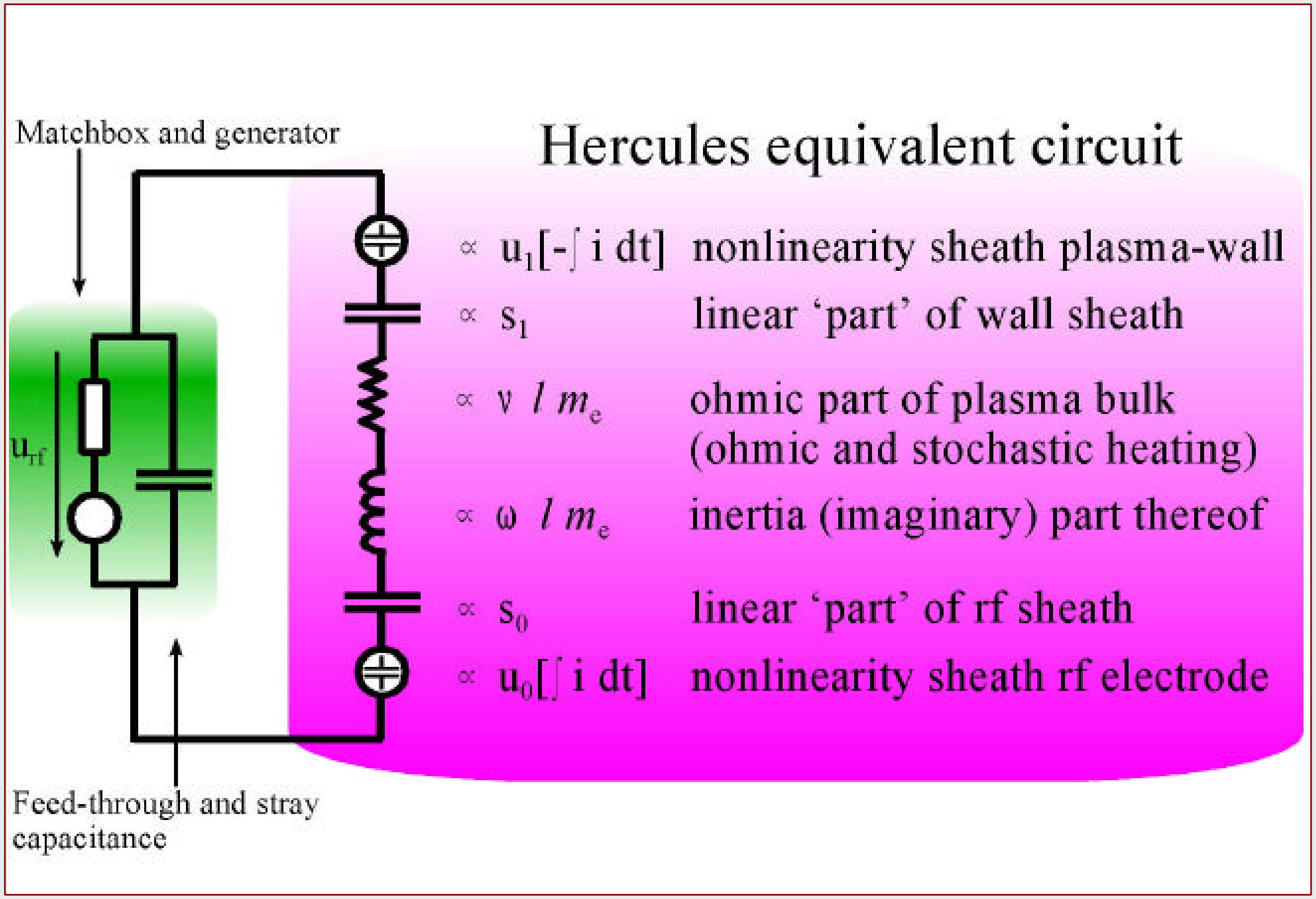
- Introduction
- Theory and setup
- Process and tool monitoring
- Engineering applications
- Summary and outlook

Basic Model of HERCULES

Self **E**xcited **E**lectron Plasma **R**esonance **S**pectroscopy



Hercules equivalent circuit

$\propto u_1[-\int i\,dt]$	nonlinearity sheath plasma-wall
$\propto s_1$	linear 'part' of wall sheath
$\propto \nu\ l\ m_e$	ohmic part of plasma bulk (ohmic and stochastic heating)
$\propto \omega\ l\ m_e$	inertia (imaginary) part thereof
$\propto s_0$	linear 'part' of rf sheath
$\propto u_0[\int i\,dt]$	nonlinearity sheath rf electrode

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Measurement principle of HERCULES

rf current
rf voltage

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FFT

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Model
SEERS

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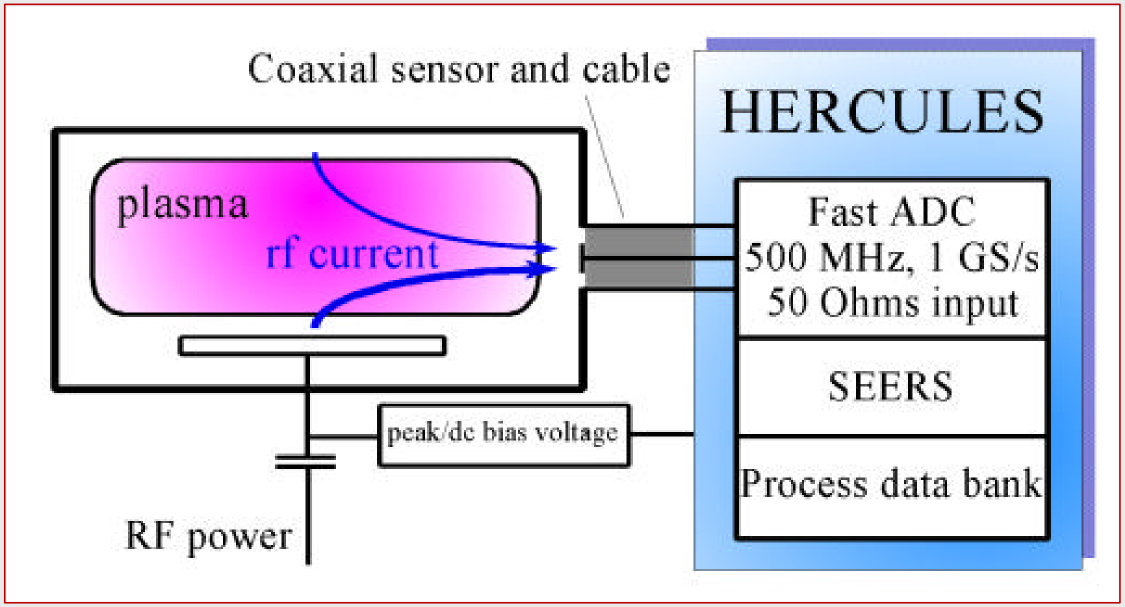
Electron collision rate
Electron density
Bulk power
DC bias voltage



- ***Passive*** electrical method, no impact on the plasma
- ***Integral*** measurement

SEERS provides reciprocally averaged parameters

Electron density:

$$\tilde{n} = \left(\frac{1}{V} \int_V n_e^{-1}\, dV \right)^{-1}$$

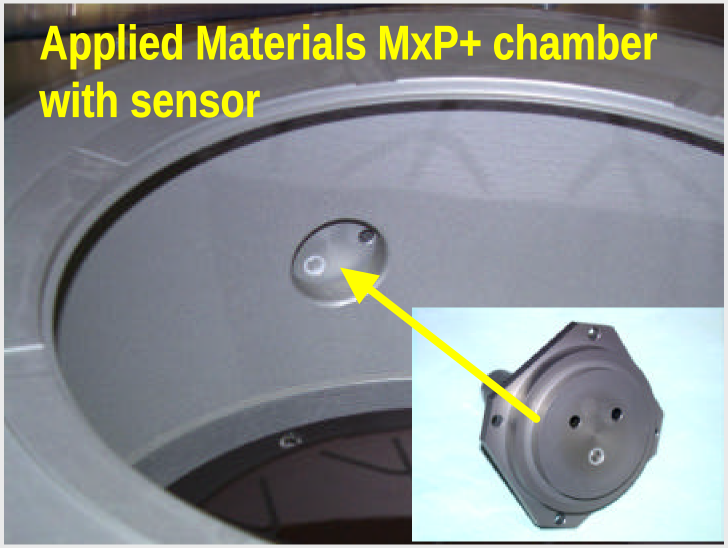
Electron collision rate:

$$\tilde{\nu} = \frac{\tilde{n}}{V} \int_V \frac{\nu}{n}\, dV$$

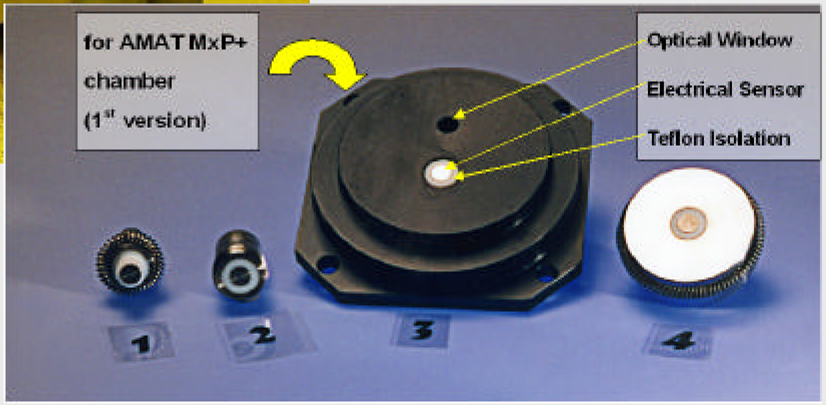
Bulk power:

$$P_B \propto \frac{\tilde{\nu}}{\tilde{n}} \sum_k \lfloor I^{(k)} \rfloor^2$$

HERCULES Equipment Setup



Applied Materials MxP+ chamber with sensor



Sensor surface: anodized aluminum, similar to chamber wall.

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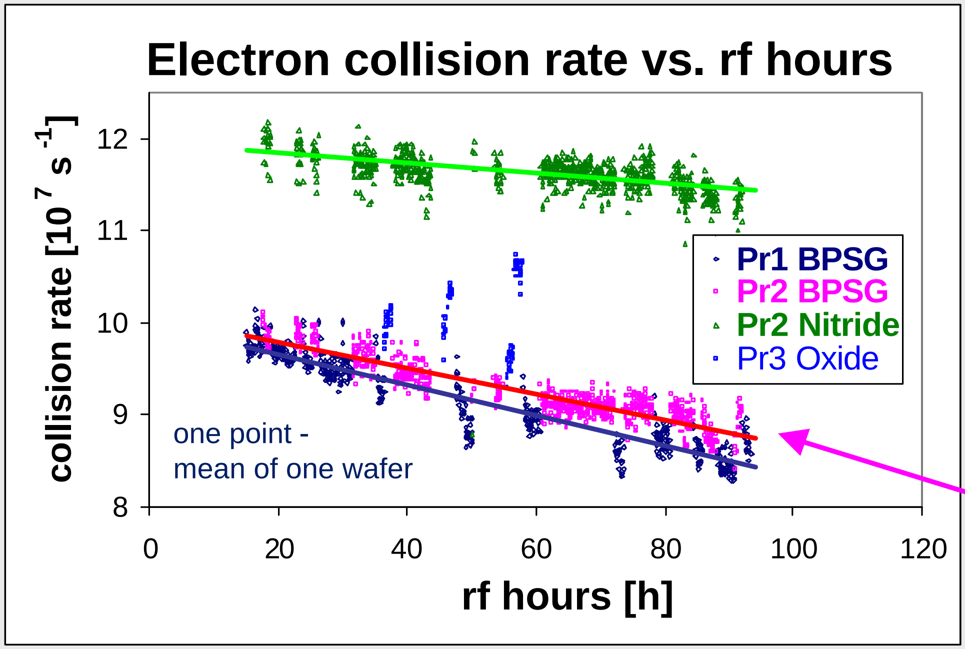
Three examples of long term process monitoring

- Three examples of process and tool monitoring results are shown now.
- Monitoring of Contact etch process at an Applied Materials MxP+ chamber.
- Monitoring of the same chamber for 14 months.
- Monitoring of three processes.

Conditioning effects on long term process stability



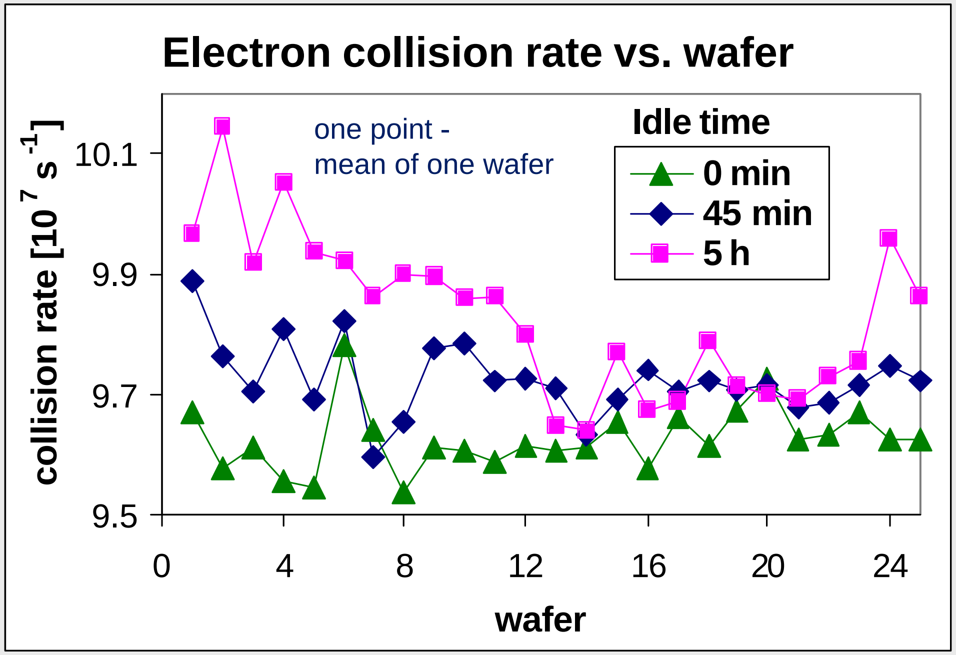
Step	**Pr 1**	**Pr 2**
pre	--	N_2 / O_2 step
main	BPSG etch	BPSG etch
over	--	Nitride etch

Contact etch at AMAT MxP+
Process monitoring of 3 products covering the period between two wet cleans.

Process 2:
deconditioning caused by pre step and over step.

Electron collision rate is very sensitive to etch chemistry.

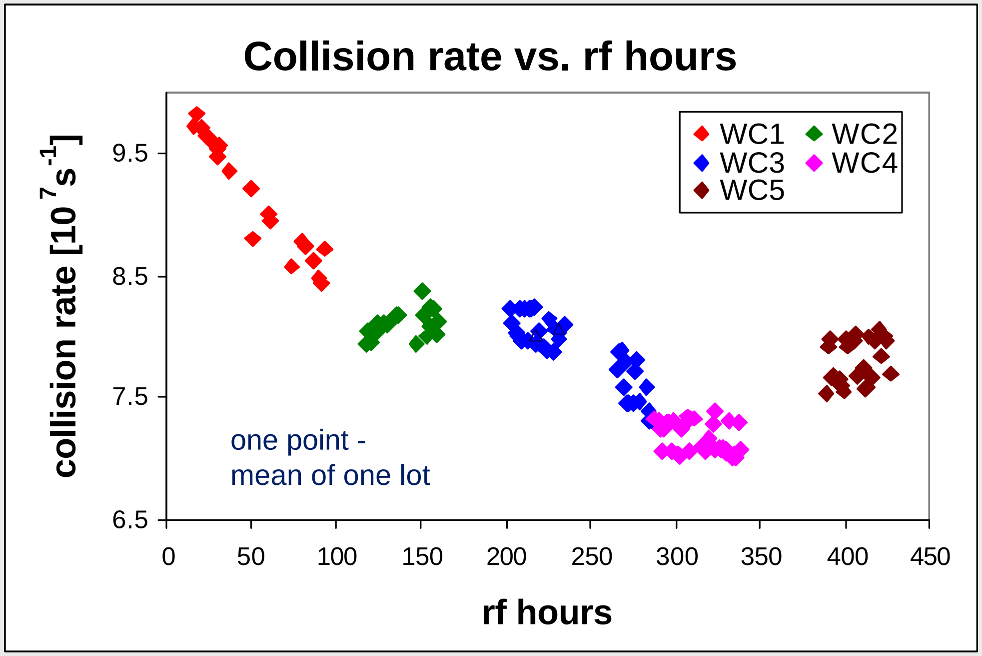
Short term chamber drift and first wafer effect



Contact etch at AMAT MxP+
Process monitoring of 3 lots of one product.

- Electron collision rate shows dependence on chamber idle time.
- “First wafer effect“: Constant chamber conditions after about 12 wafers !
- Expected reasons: Temperature equilibrium and gas adsorption at liner wall.

Tool related effects on long term process stability



Contact etch at AMAT MxP+
Process monitoring of product wafers of one product for 5 wet clean cycles, more than 6 months.

- Wet clean (WC) depending drift effect, hardware reason (not found yet):
- **WC1**, **WC3** chamber drift
- **WC2**, **WC4**, **WC5** stable chamber conditions on varying level

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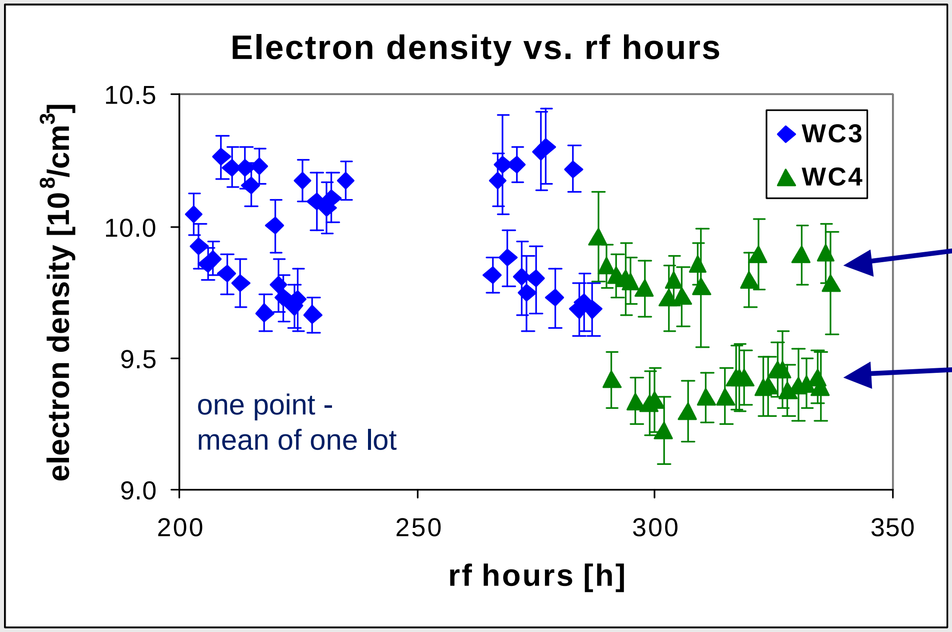
S. Bernhard
M. Sussiek
C. Steuer

Open area impact on plasma parameters



- One recipe for two products.

Product 1

Product 2

- Impact of open area on electron density.

Contact etch at AMAT MxP+
Process monitoring of product wafers of one product for 5 wet clean cycles, more than 6 months.

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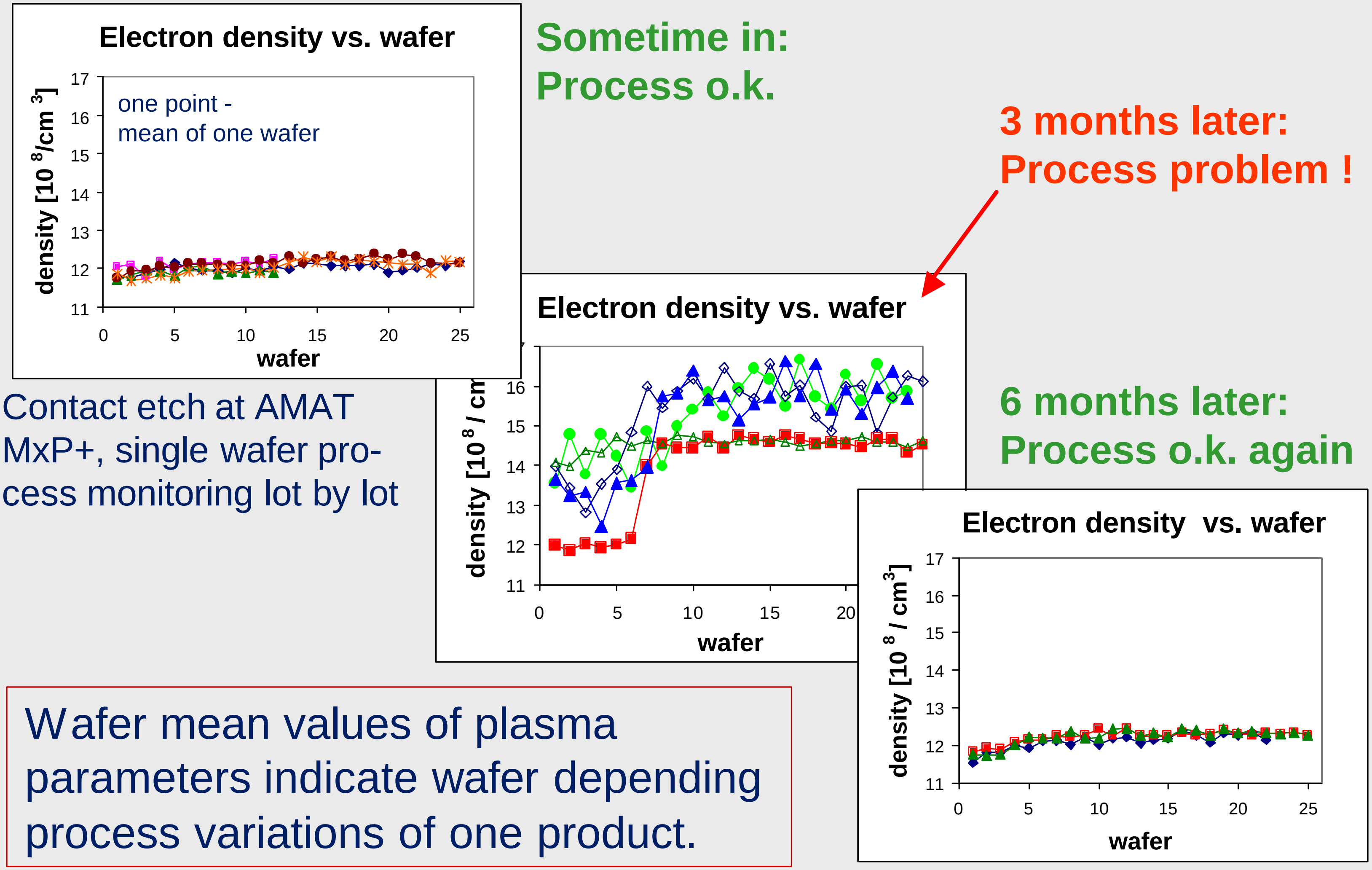
Process & Tool Monitoring 1st example

Summary of the 1st process monitoring example

- Conditioning effect
- “First wafer” effect: Temperature drift & gas adsorption
- Impact of chamber kit and wet clean procedure
- Impact of open area
- But no impact of all these variations on yield.
- The monitoring system can detect small process variations, which can still be neglected by that product.
- This should be the normal situation,
  the process runs well !

Single wafer control of process stability



Sometime in:
Process o.k.

3 months later:
Process problem !

6 months later:
Process o.k. again

Contact etch at AMAT MxP+, single wafer process monitoring lot by lot

Wafer mean values of plasma parameters indicate wafer depending process variations of one product.

A. Steinbach
S. Bernhard
M. Sussiek
C. Steuer

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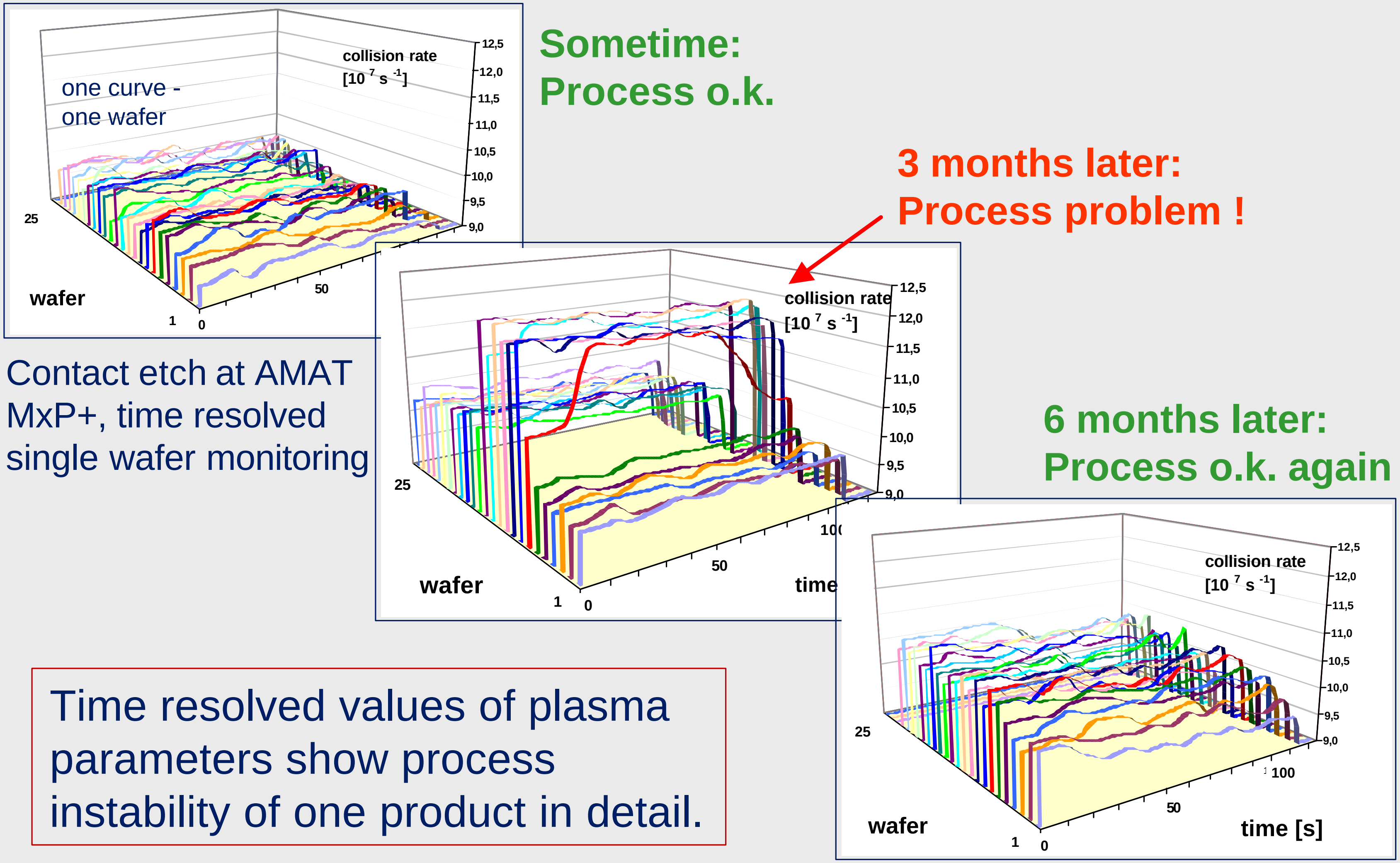
Process & Tool Monitoring 2nd example

Time resolved results of single wafer control



Sometime:
Process o.k.

3 months later:
Process problem !

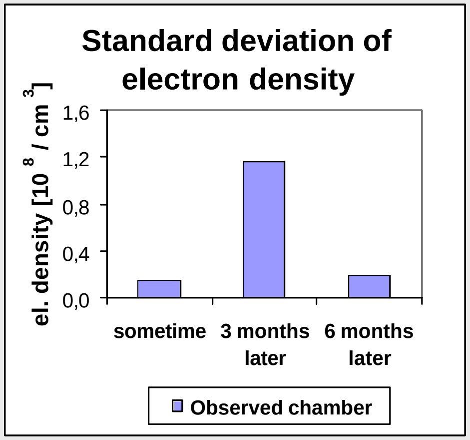
6 months later:
Process o.k. again

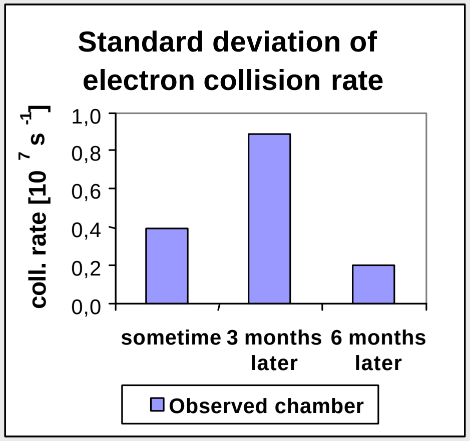
Contact etch at AMAT MxP+, time resolved single wafer monitoring

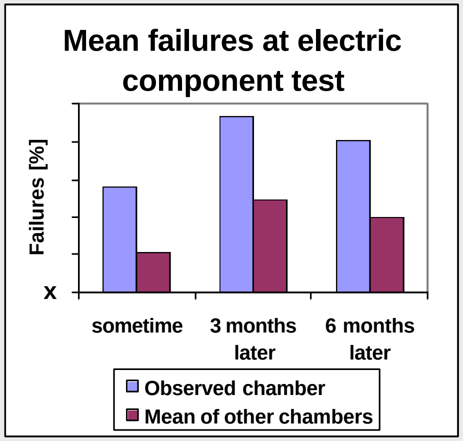
Time resolved values of plasma parameters show process instability of one product in detail.

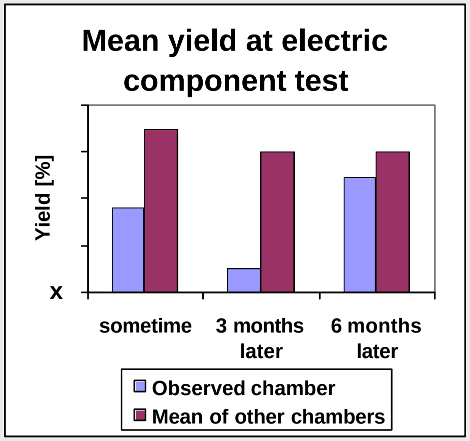
Process & Tool Monitoring 2nd example

Correlation between plasma parameters, failures at electrical component test & yield


Standard deviation of electron density


Standard deviation of electron collision rate


Mean failures at electric component test


Mean yield at electric component test

- Correlation between standard deviations of plasma parameters, electrical failure counts and yield.
- Process problem impacts all chambers, used for Contact etch.
- Process problem increases tool related differences between chambers.

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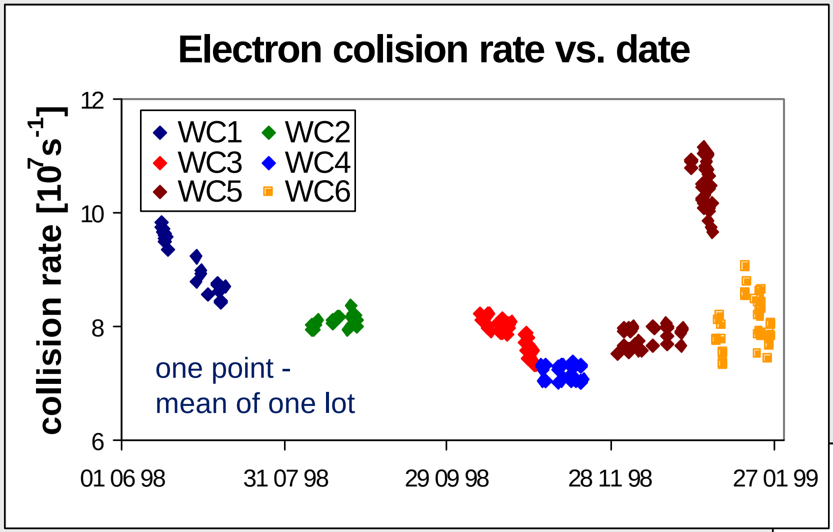
Summary of the 2nd process monitoring example

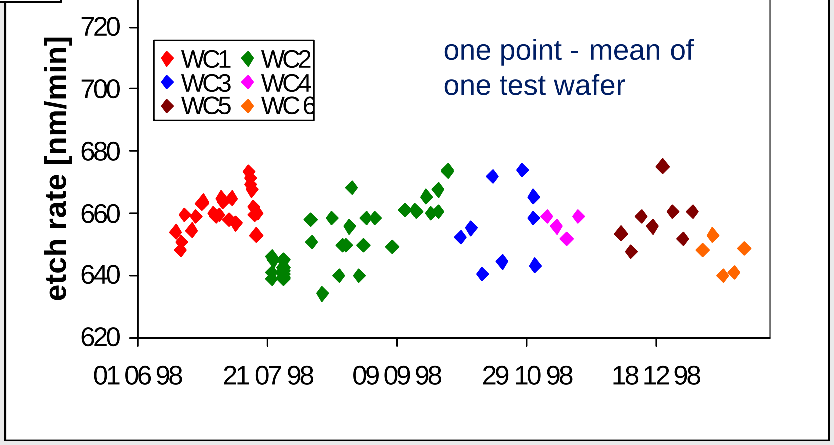
- Plasma parameter standard deviations of one product correlate with electrical failure counts and yield loss.
- Electron collision rate and electron density at Contact etch indicate process problems at a pre- process of this one product.
- A serious process problem was indicated in real time by plasma monitoring with Hercules.

Real time detection of hardware failure



Increase of mean values of plasma parameters on all products indicate a hardware failure at the chamber.

Contact etch at AMAT MxP+



Oxide etch rate measurement on blank test wafers ***does not show*** any significant variation.

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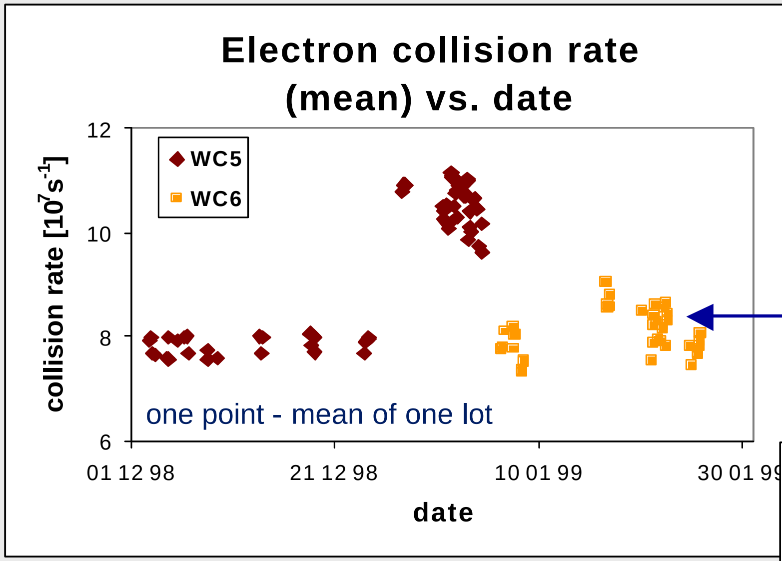
Process & Tool Monitoring 3rd example

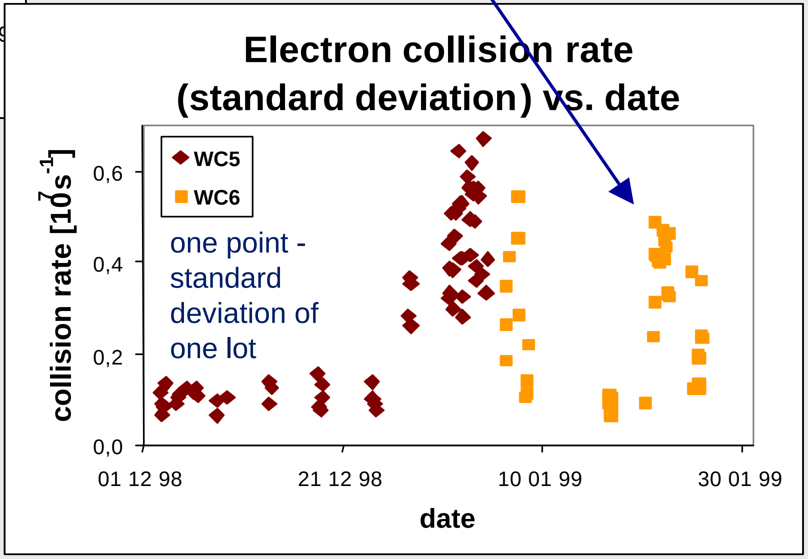
Comparison between mean and standard deviation of plasma parameters


Electron collision rate (mean) vs. date

one point - mean of one lot

Standard deviation shows higher sensitivity to process instability.

Contact etch at AMAT MxP+

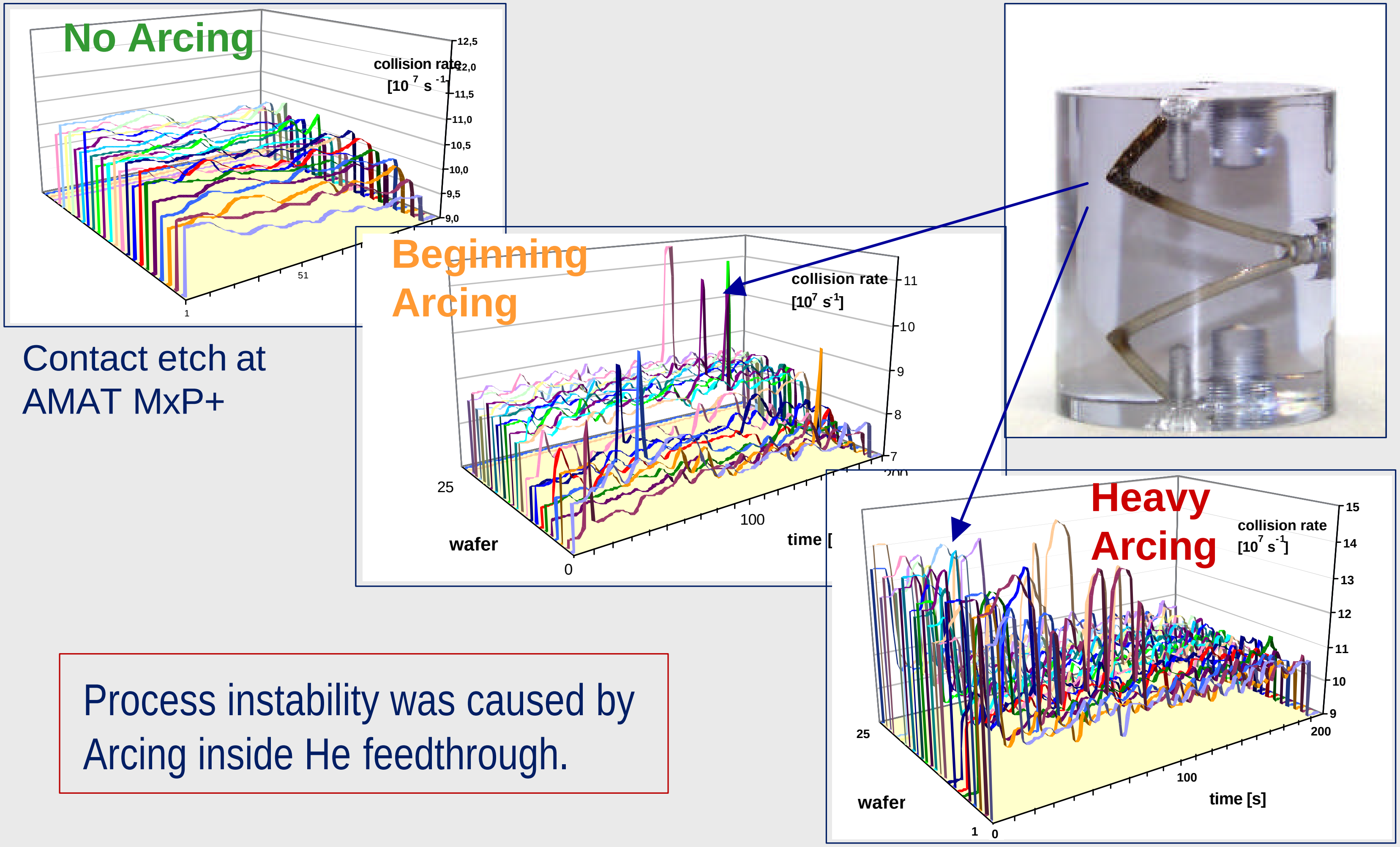

Electron collision rate (standard deviation) vs. date

one point - standard deviation of one lot

A. Steinbach
S. Bernhard
M. Sussiek
C. Steuer

Process & Tool Monitoring 3rd example

Hercules detects arcing inside He feedthrough of Applied Materials MxP+ chamber



Contact etch at AMAT MxP+

Process instability was caused by Arcing inside He feedthrough.

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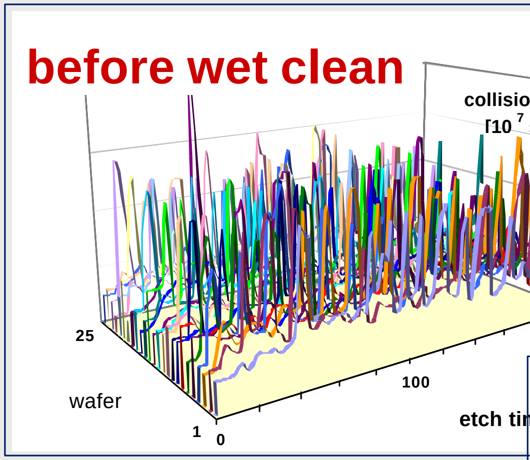
Summary of the 3rd process monitoring example

- Plasma parameter standard deviations of all kinds of wafers indicate tool problem.
- Plasma parameters are much more sensitive as etch rate test on blanket oxide wafers.
- Arcing inside He feedthrough has been detected in real time, immediately.
- Early tool failure detection allows preventive maintenance measures and prevents yield loss.

Engineering applications

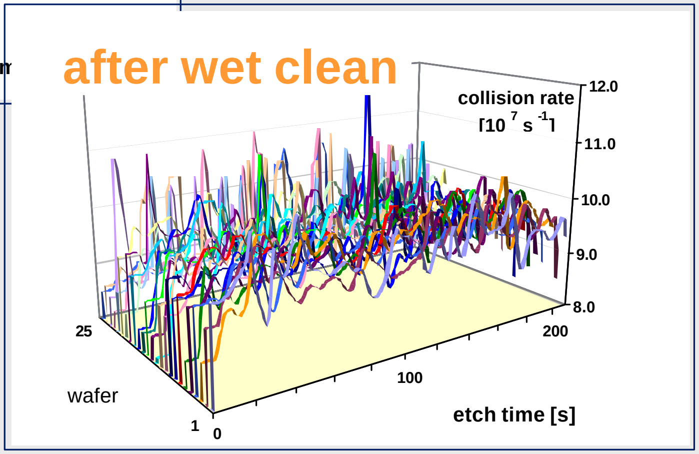
- Four examples of engineering applications are shown now:
  - Monitoring of maintenance measures
  - Optimisation of a conditioning procedure
  - Chamber comparison
  - RF match box evaluation

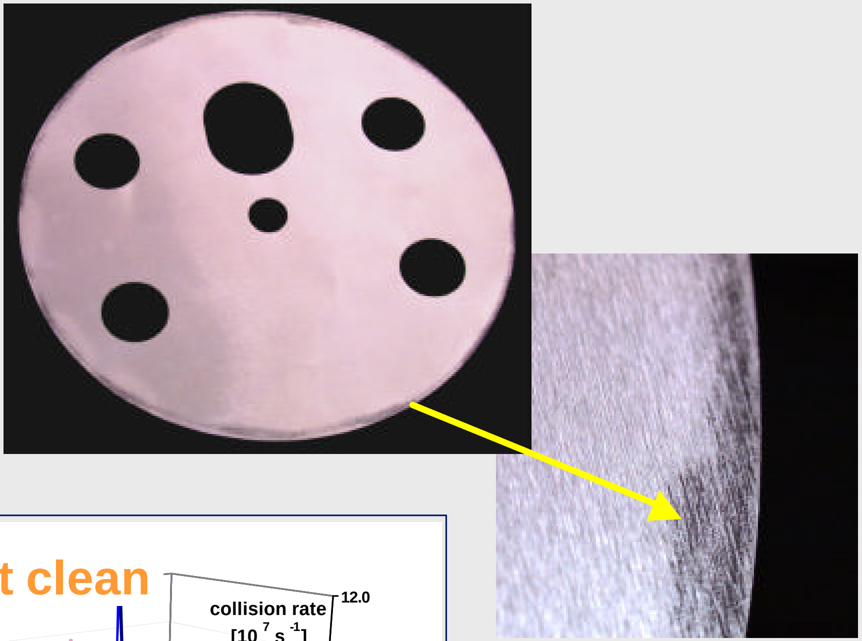
Monitoring of maintenance activities - Example: Arcing detection at AMAT MxP+



Contact etch at AMAT MxP+

Arcing below electro-static chuck at Al foil.





Arcing problem was not fixed by wetclean.

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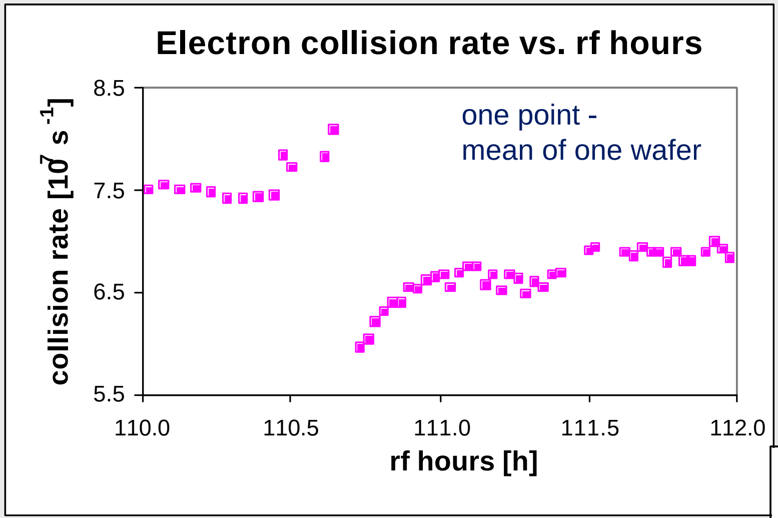
Engineering 1st application

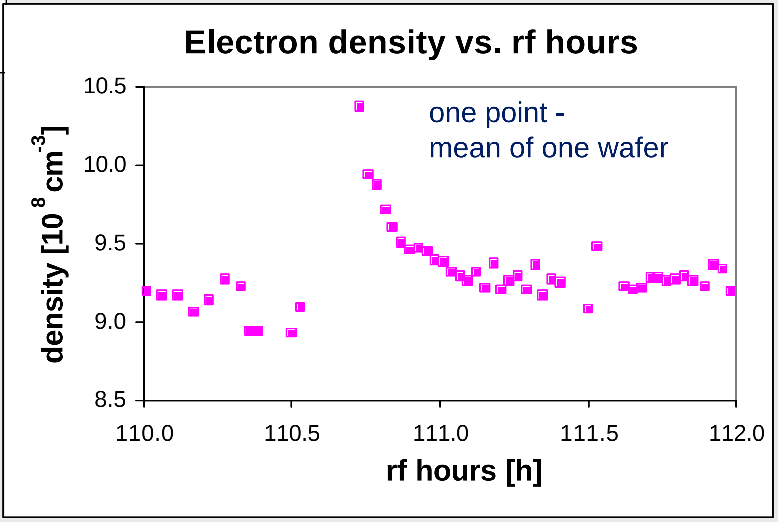
Optimisation of conditioning after wet clean



- Effect of chamber clean shows up in the electron collision rate.
- About 10 wafers are necessary to reach stable chamber conditions again.

Contact etch at AMAT MxP+

- Optimization of conditioning procedures ➔
  Non - Productive
  Wafer reduction



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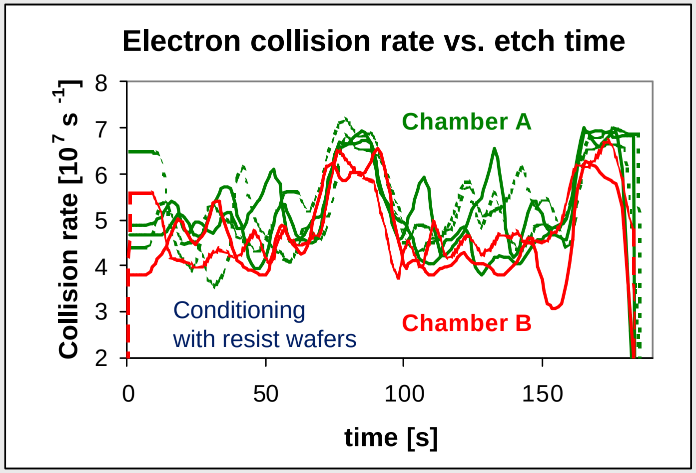
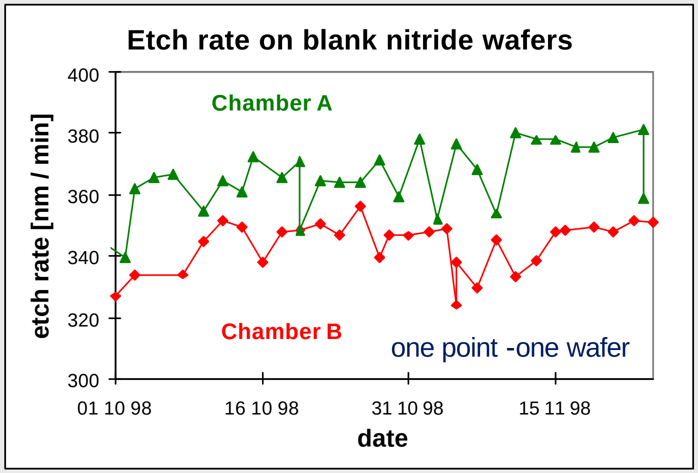
Engineering 2nd application

Tool and chamber comparison by power density measurement



Parameter	Ratio Ch A/Ch B
Nitride etch rate	1,17
Electron collision rate	1,19
Bulk power	1,21

- **Chamber A** and **Chamber B** with "identical" conditions.
- Nitride etch rate ratio correlates with ratios of el.col.rate and bulk power.
- Lower etch rate caused by lower power density.



Nitride etch at AMAT MxP

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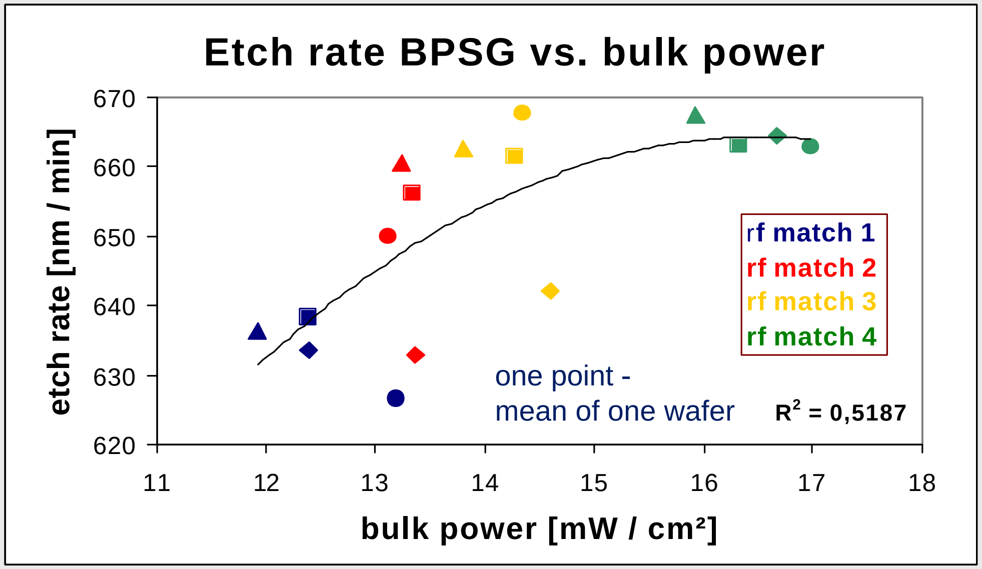
RF matchbox comparison by power density measurement



Contact etch at AMAT MxP+

Comparison of power dissipation inside the chamber, while nominal rf power kept constant.

- RF match box comparison by bulk power measurement.
- Power coupling into the chamber differs about 30% as indicated by bulk power.
- Impact of chamber conditions.
- Oxide etch rate saturation at high power dissipation (rf match 4) possibly caused by transport processes or surface reactions.

Summary

- Hercules, based on SEERS, has been used for long term process and tool monitoring and engineering tasks.
- The plasma parameters depend on process parameters, tool conditions and wafer impacts.
- Therefore process and tool related problems as well as wafer depending effects were detected.
- Interesting applications are: Early failure detection
  Arcing monitoring
  Tool & chamber matching