Application of the Plasma Monitoring System HERCULES on process monitoring of oxide etch at Applied Materials MxP+ chamber

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Contents

- Theory and setup
- Basic experiments
- Results of long term process and tool monitoring
- Summary and outlook

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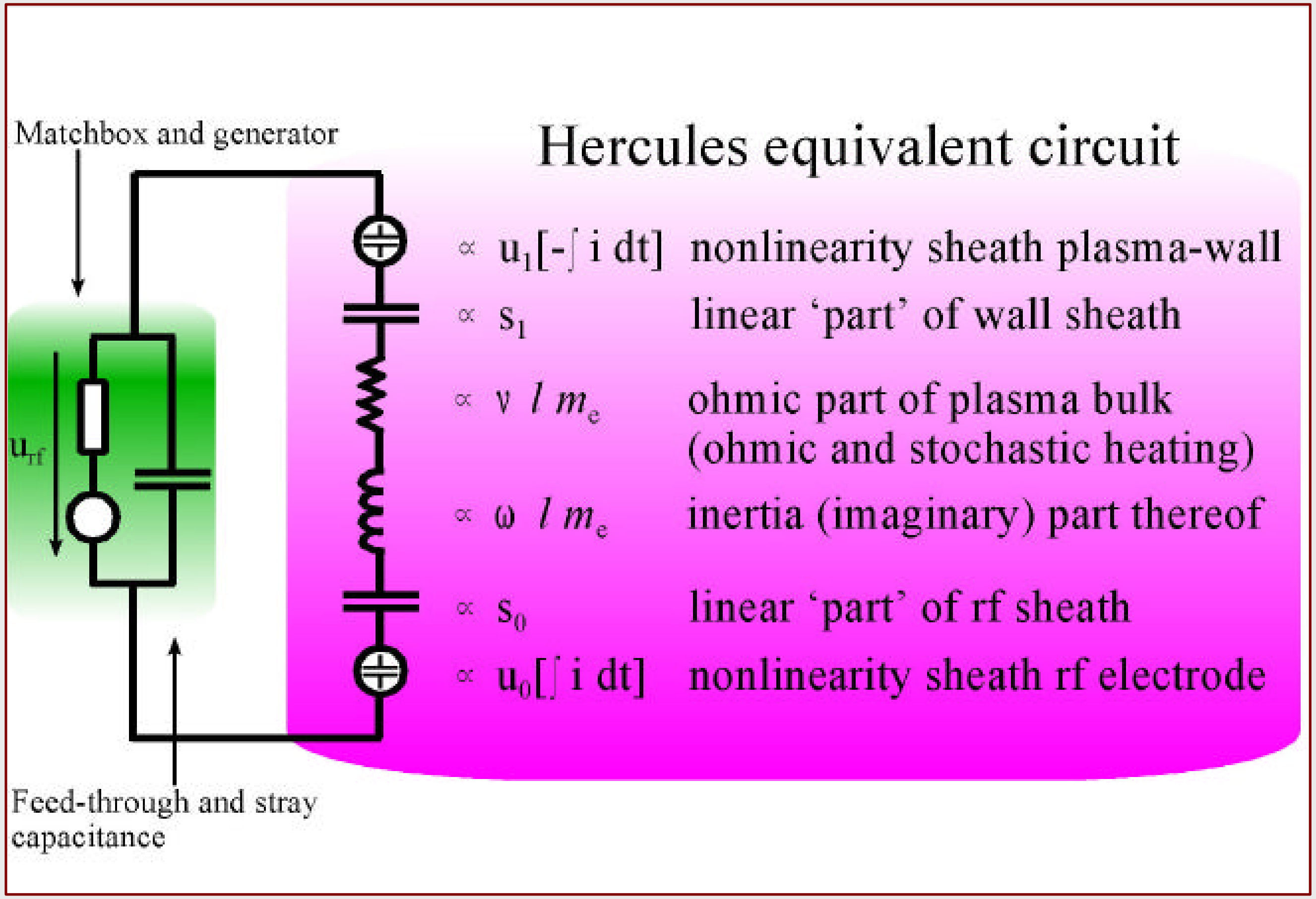
Basic Model of HERCULES

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



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Measurement principle of HERCULES

rf current
rf voltage

↓

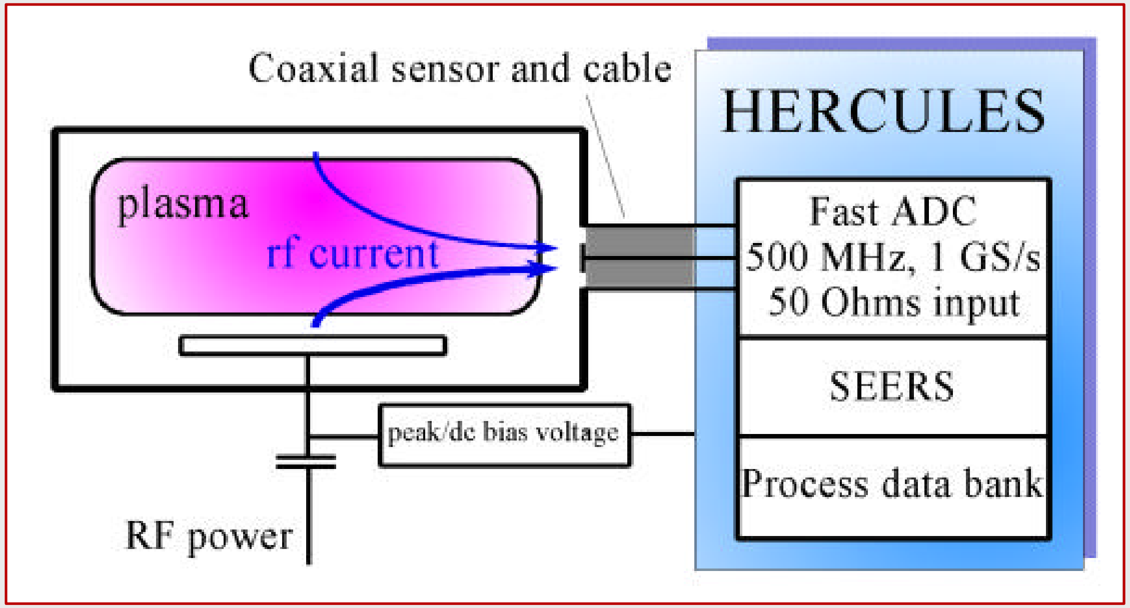
F F T

↓

Model
SEERS

↓

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:
$$P_B \propto \frac{\tilde{\nu}}{\tilde{n}} \sum_k \left| I^{(k)} \right|^2$$

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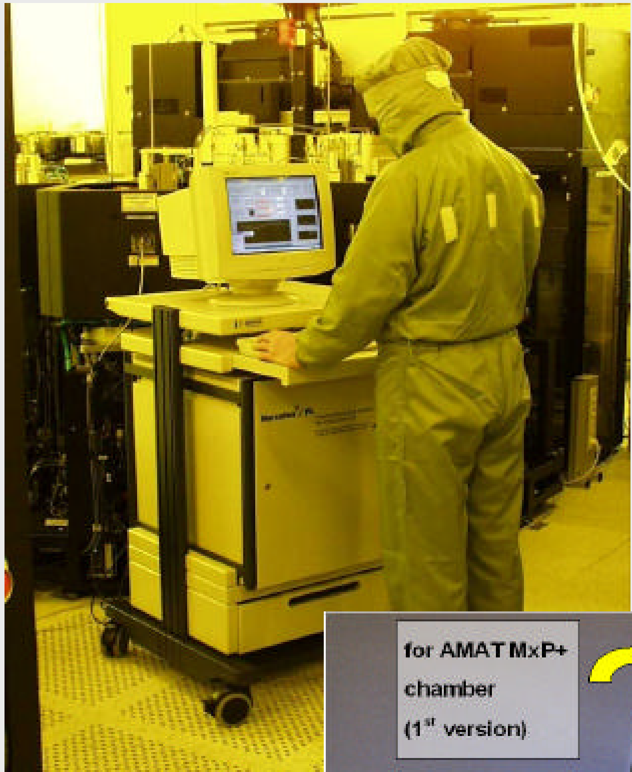
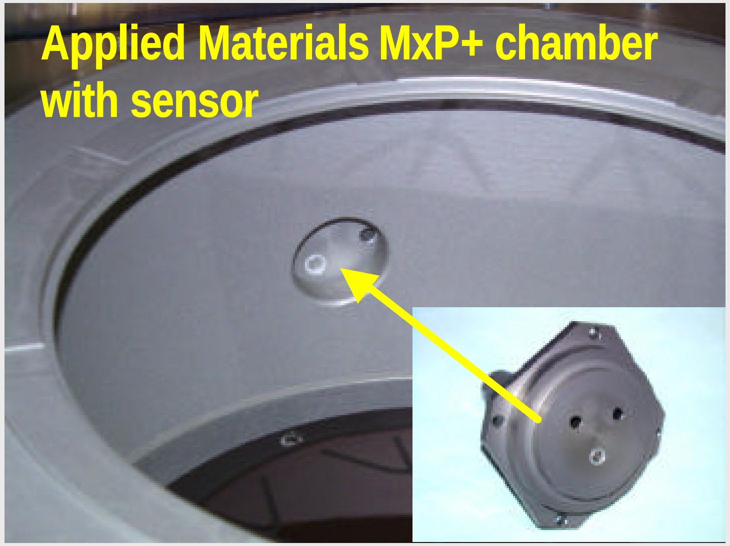
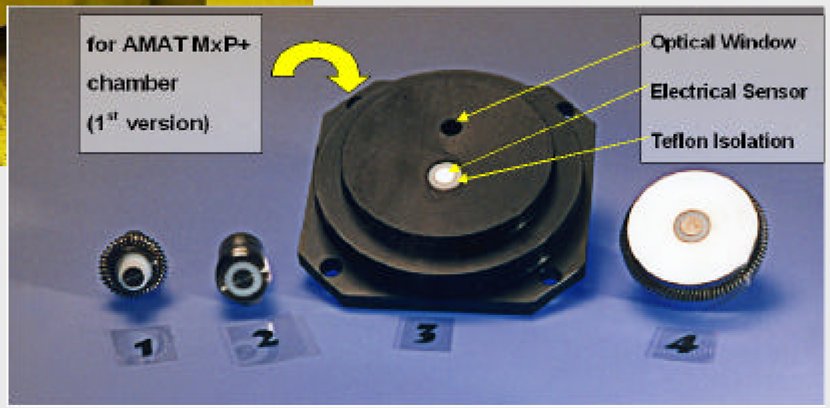
HERCULES Equipment Setup







Sensor surface: anodized aluminum, similar to chamber wall.

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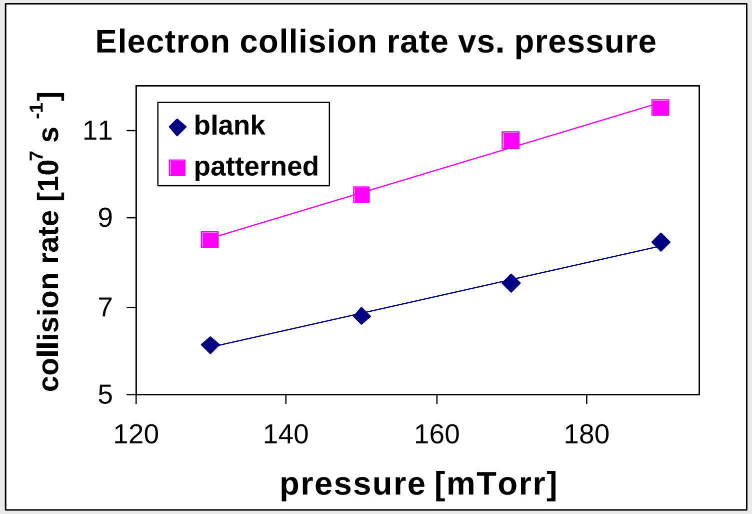
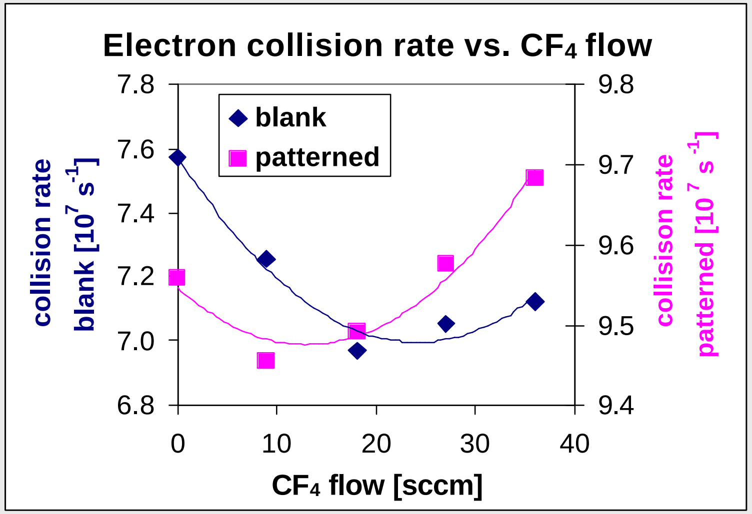
Correlation between plasma parameters and process parameters: Contact etch at MxP+



Variation of "chemical" process parameters, e.g., flow of reactive gases ➔
often strong nonlinear effects

Variation of "physical" process parameters,
e.g., pressure, rf power ➔
monotonous response,
mainly linear correlations



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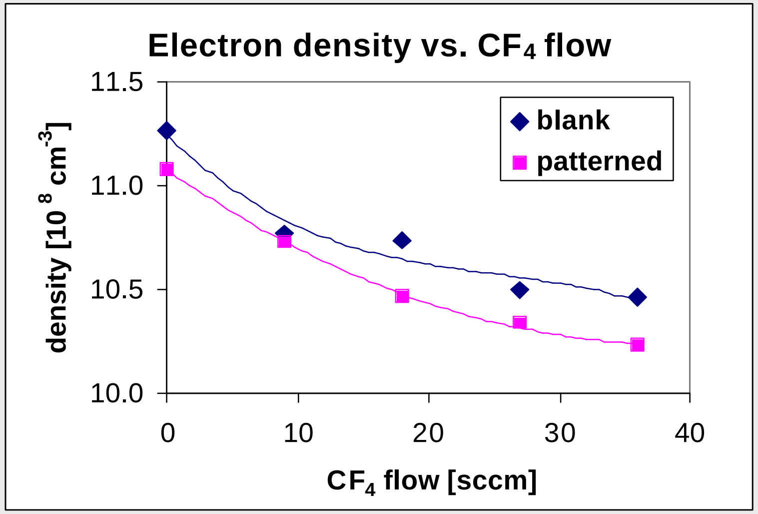
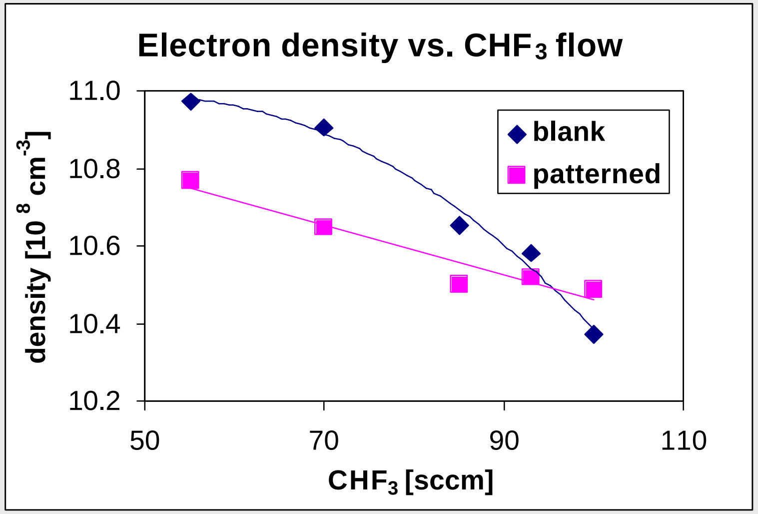
Correlations between electron density and gas flows: Contact etch an MxP+





CF_4, CHF_3, Ar, O_2 chemistry: CF_4- or CHF_3- flow increases
➔ higher F- concentration
➔ electron density decreases

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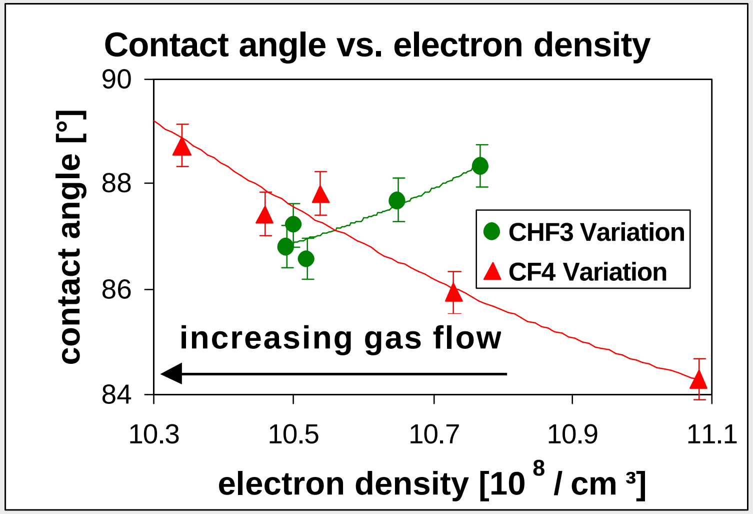
Correlations between plasma parameters and etch results: Contact etch at MxP+



Increasing CF_4- flow: F, CF_2 ↗

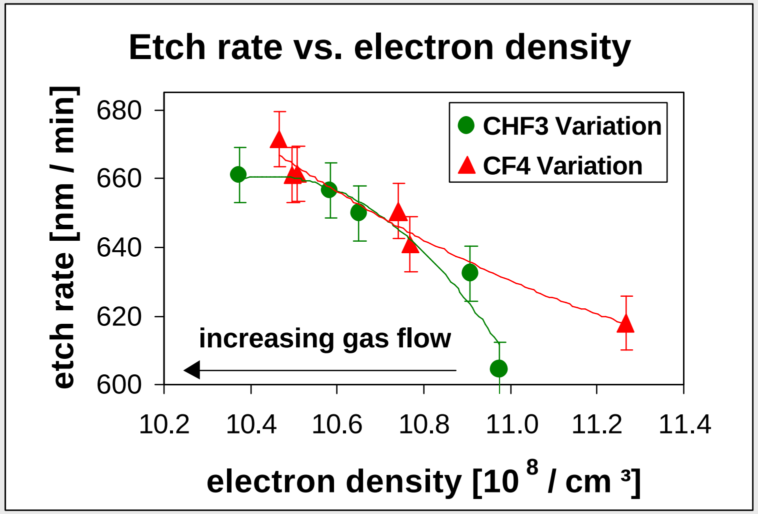
➔ oxide etch rate on blank wafers ↗

➔ lower side wall passivation on structure wafers. contact angle ↗

Increasing CHF_3- flow:

F ↗ ➔ oxide etch rate on blank wafers ↗

CHF_x ↗ ➔ higher side wall passivation on structure wafers, contact angle ↘



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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.

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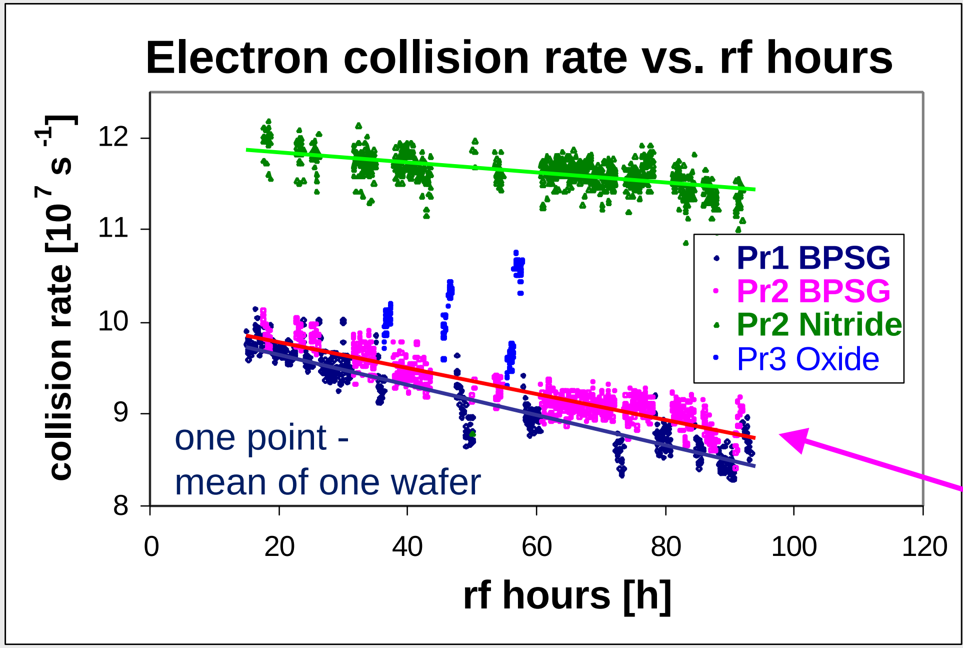
Conditioning effects on long term process stability



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.

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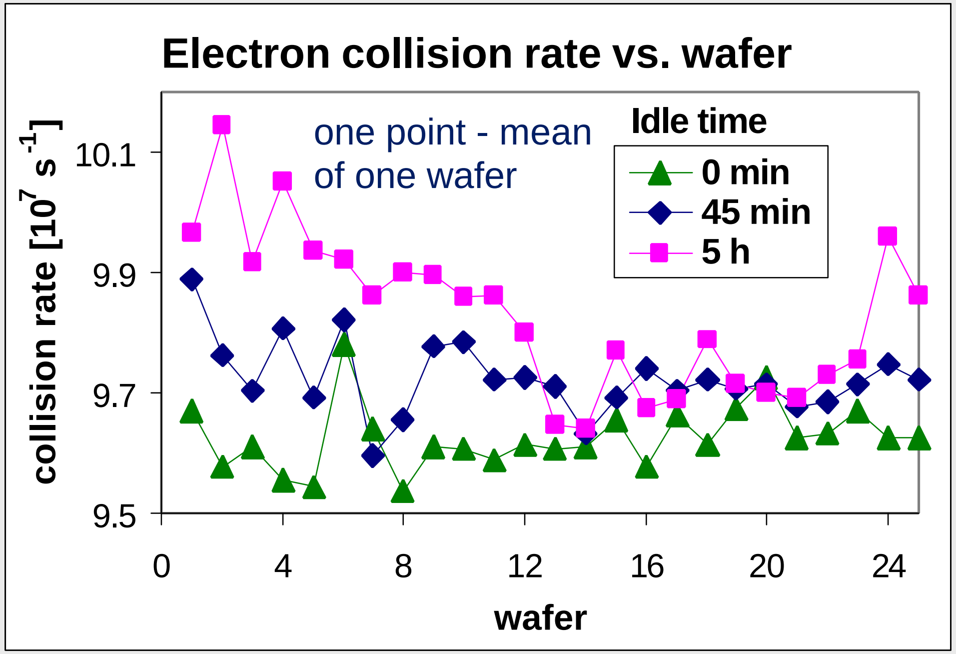
Short term chamber drift and first wafer effect



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.

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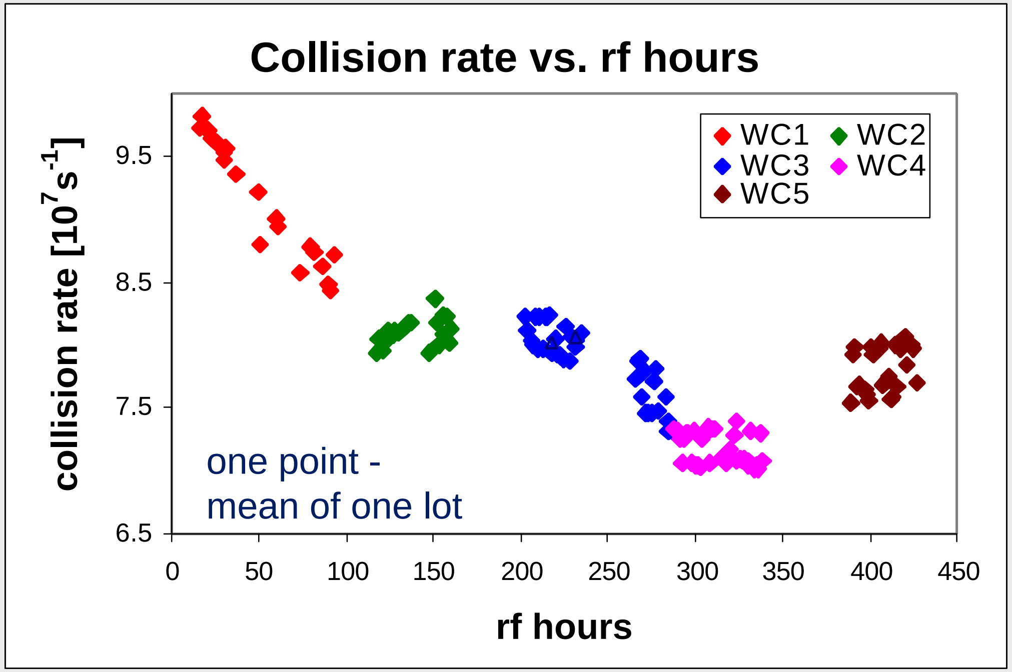
Tool related effects on long term process stability



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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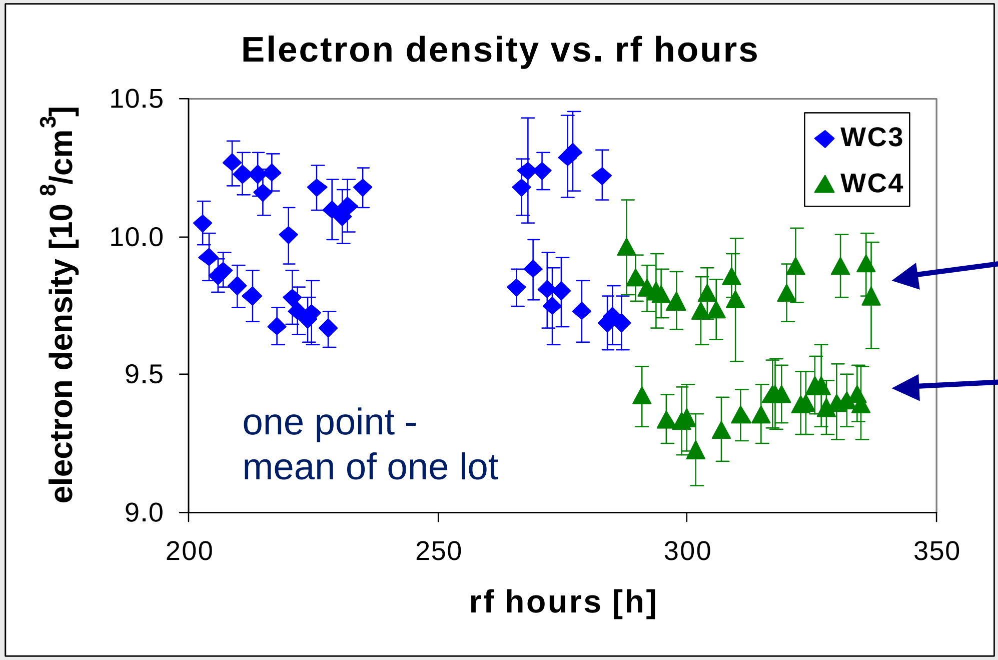
Open area impact on plasma parameters



- 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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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 !

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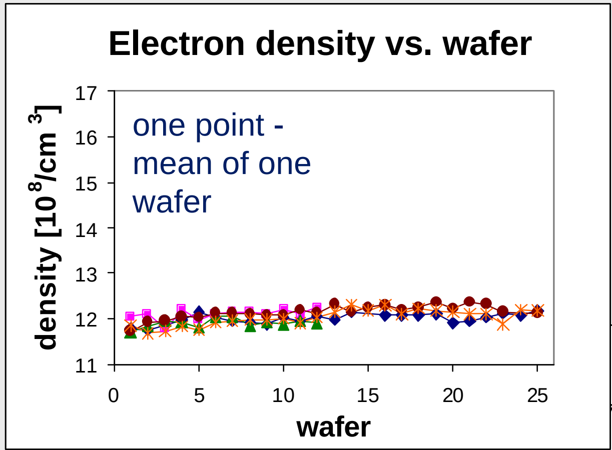
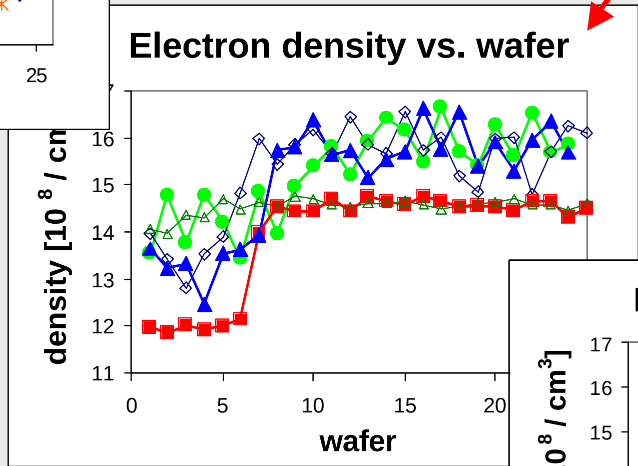
Single wafer control of process stability

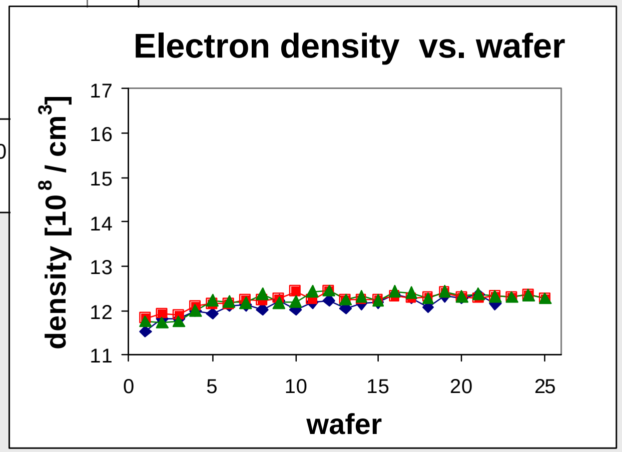


Sometime in 1998:
Process o.k.

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.

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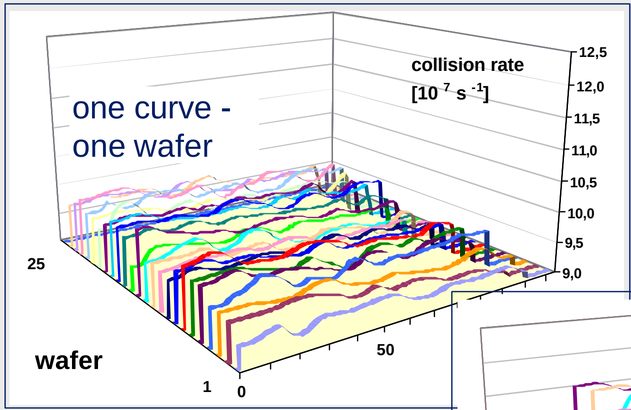
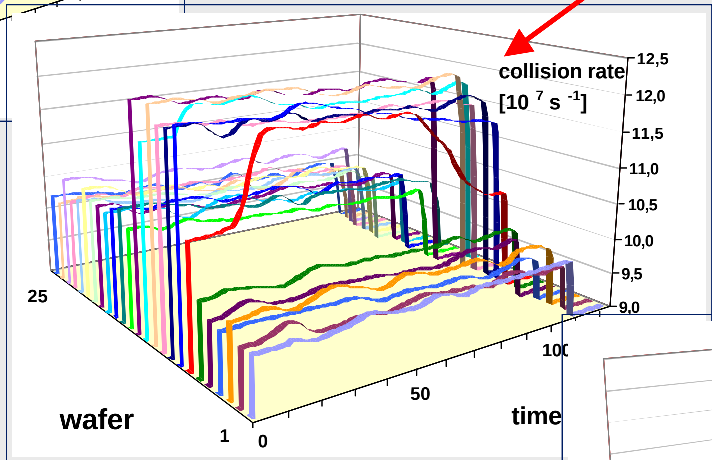
Time resolved results of single wafer control



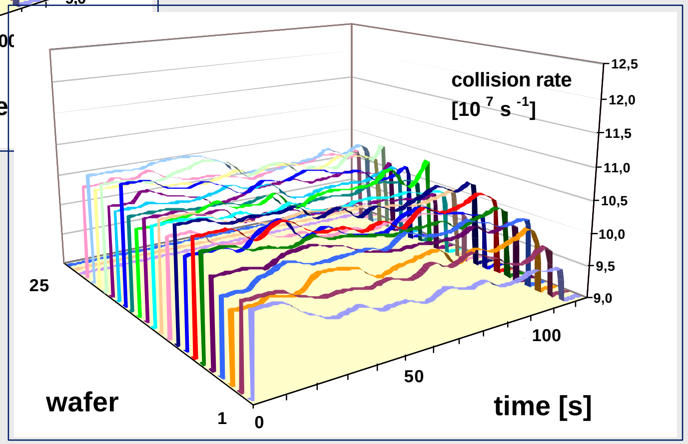
Sometime in 1998:
Process o.k.

3 months later:
Process problem !



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

6 months later:
Process o.k. again



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

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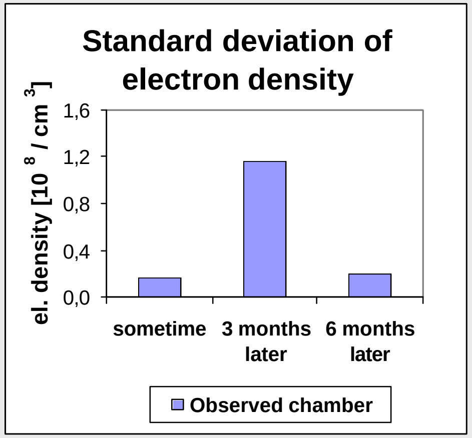
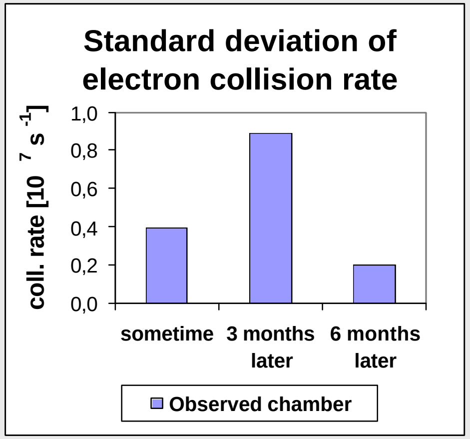
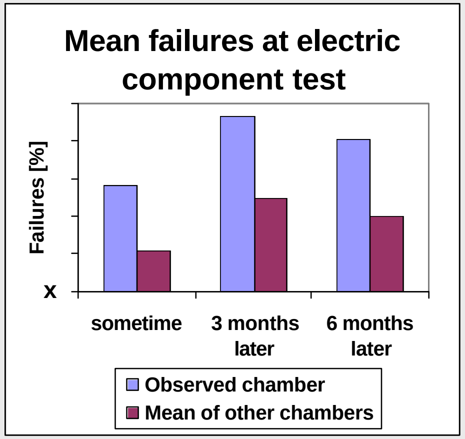
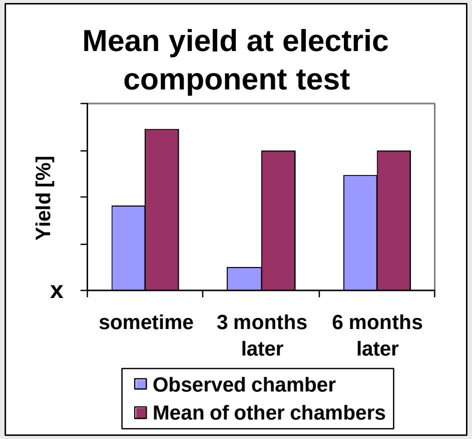
Correlation between plasma parameters, failures at electrical component test & yield









- 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.

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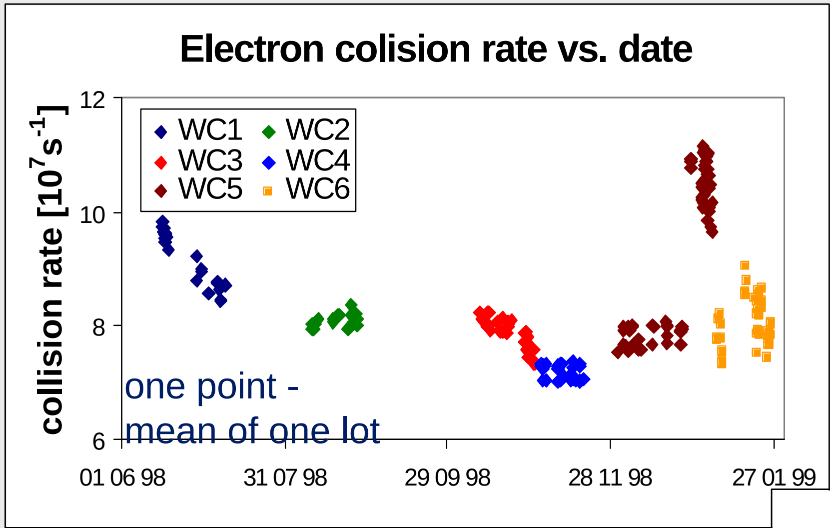
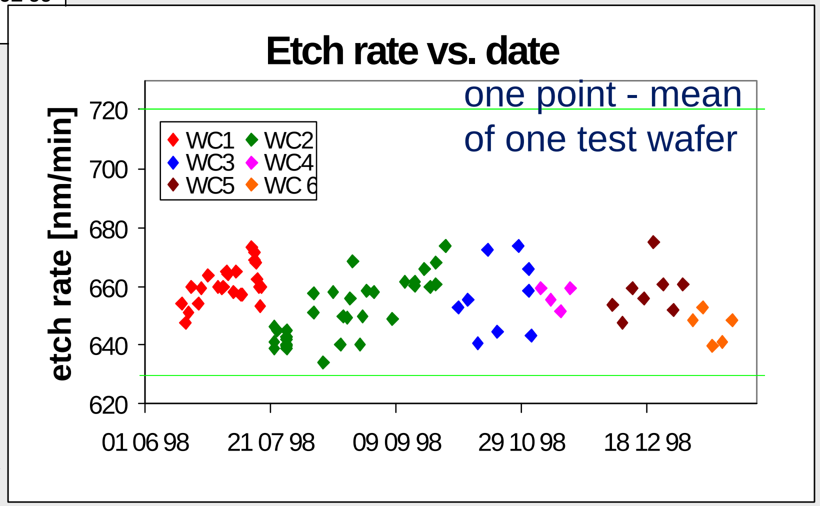
Real time detection of hardware failure



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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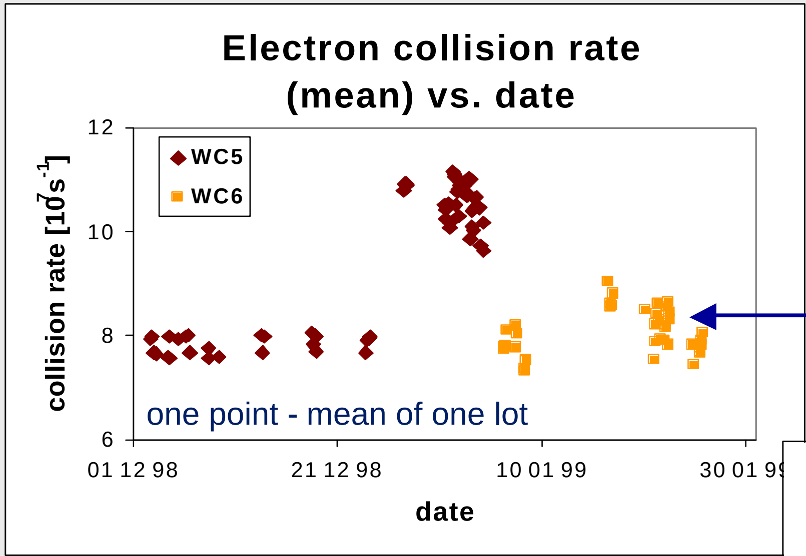
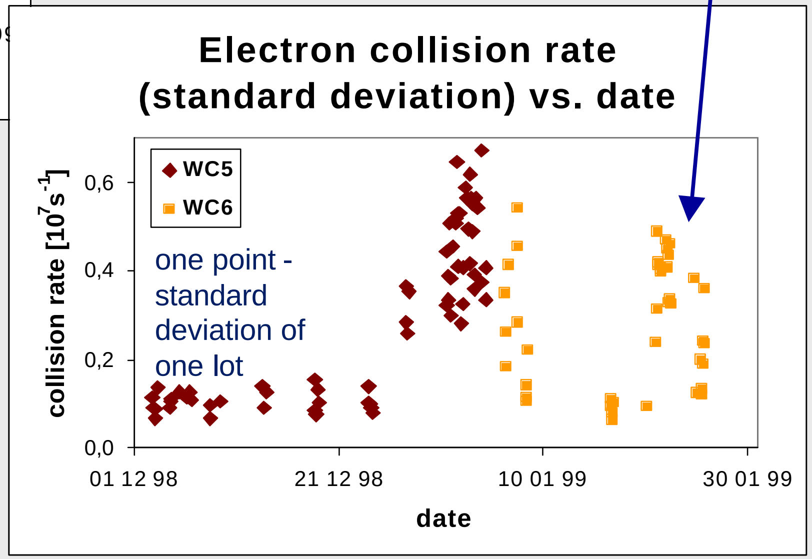
Comparison between mean and standard deviation of plasma parameters



Standard deviation shows higher sensitivity to process instability.



Contact etch at AMAT MxP+

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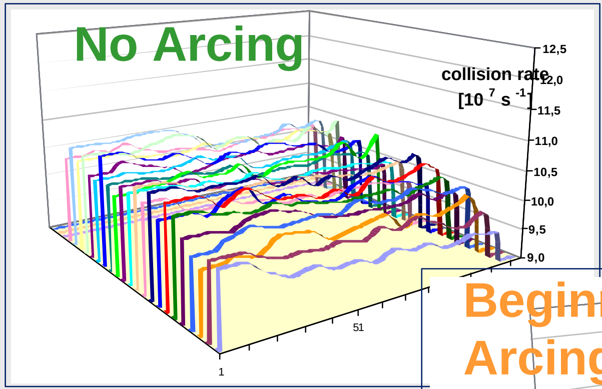
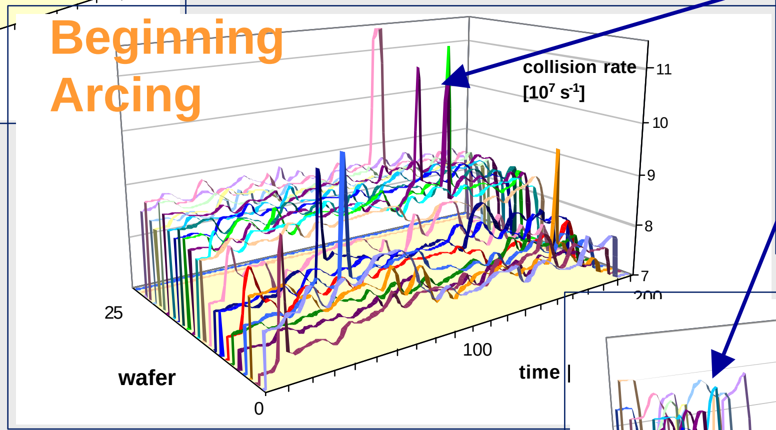
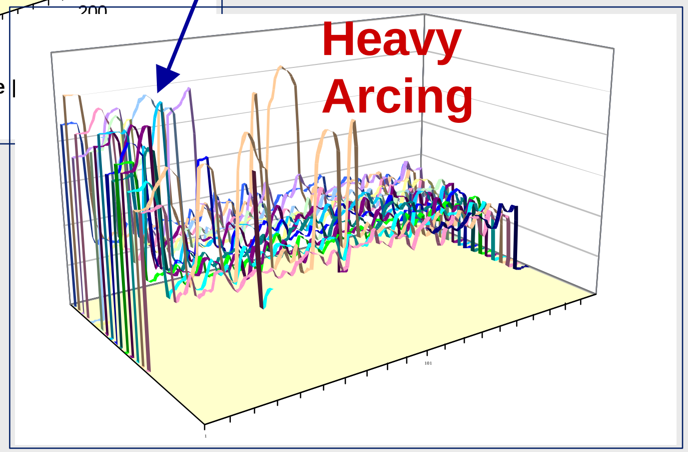
Hercules detects arcing inside He feedthrough of Applied Materials MxP+ chamber



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.

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Summary

- Hercules has been used for long term process and tool monitoring.
- The plasma parameters are real process parameters. They depend on tool conditions and wafer impacts.
- Therefore plasma parameters can be used for detection of tool related problems as well as wafer related effects.

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