

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

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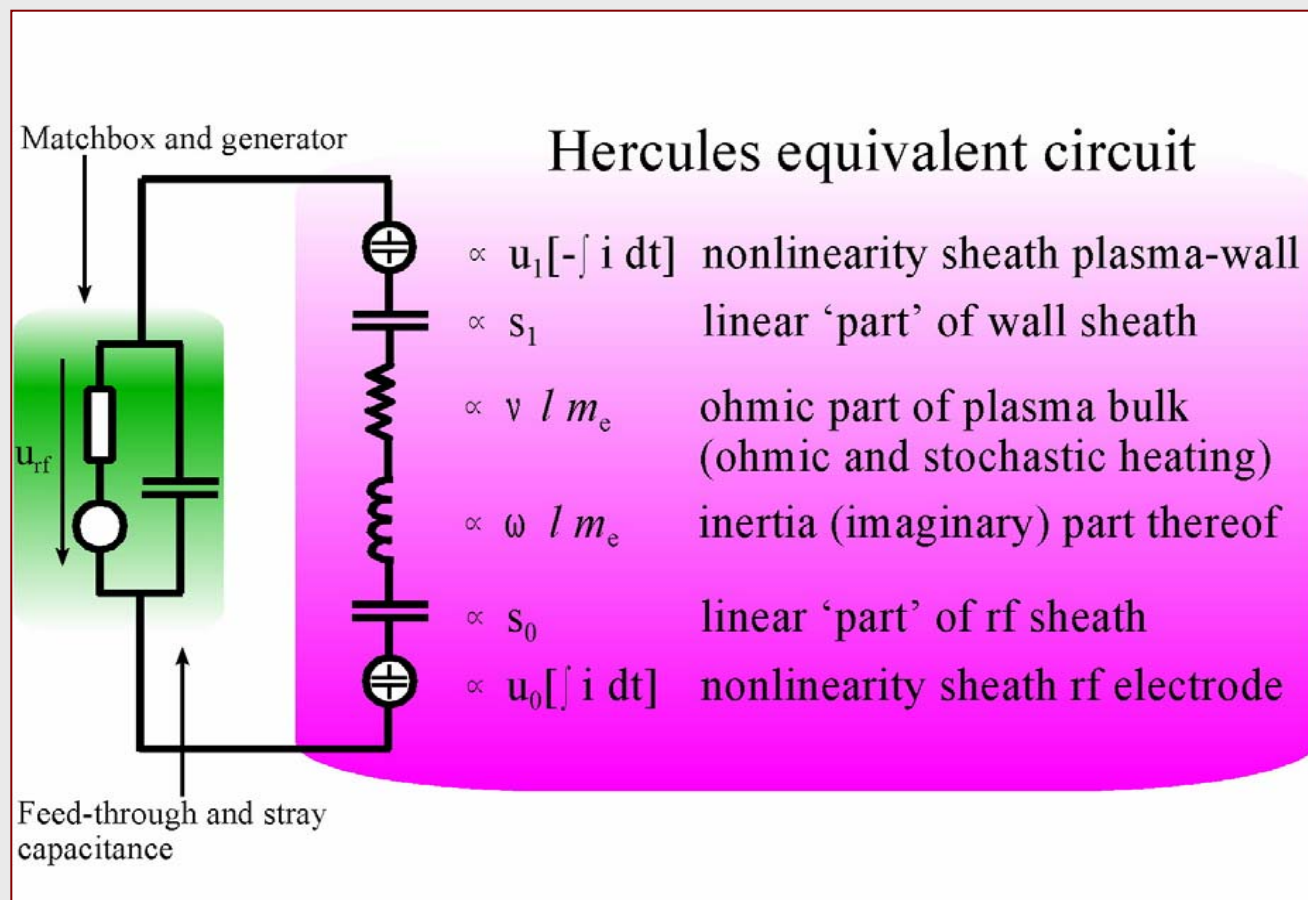
# Contents

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



# Basic Model of HERCULES

## Self Excited Electron Plasma Resonance Spectroscopy



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# Measurement principle of HERCULES

rf current  
rf voltage



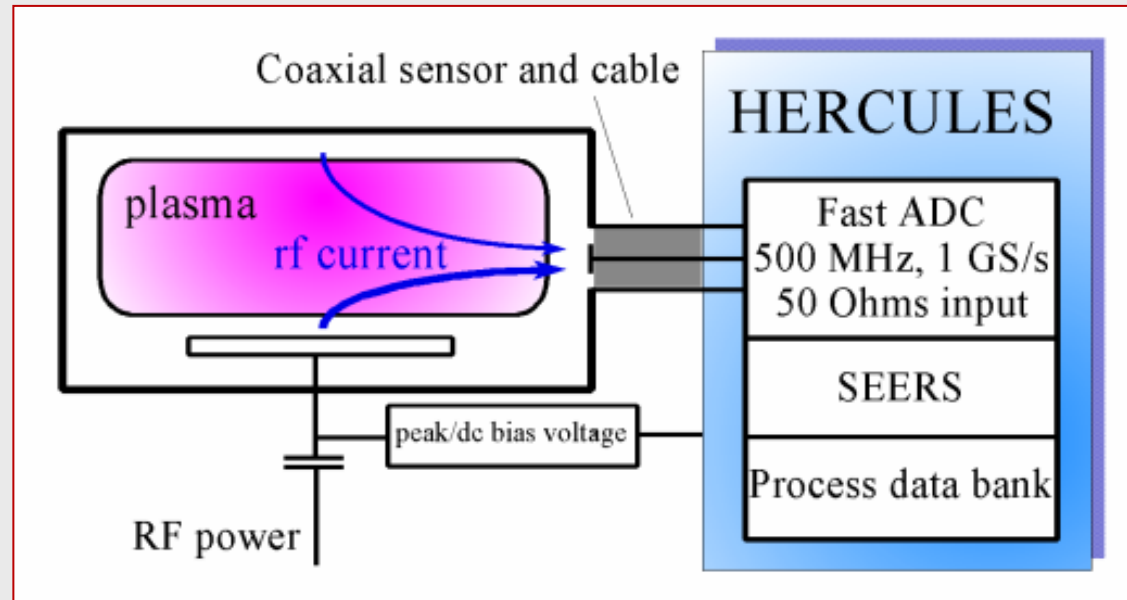
FFT



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 :*

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

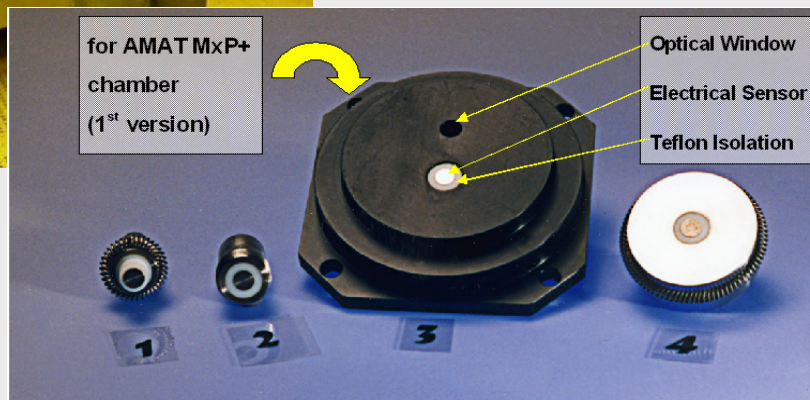
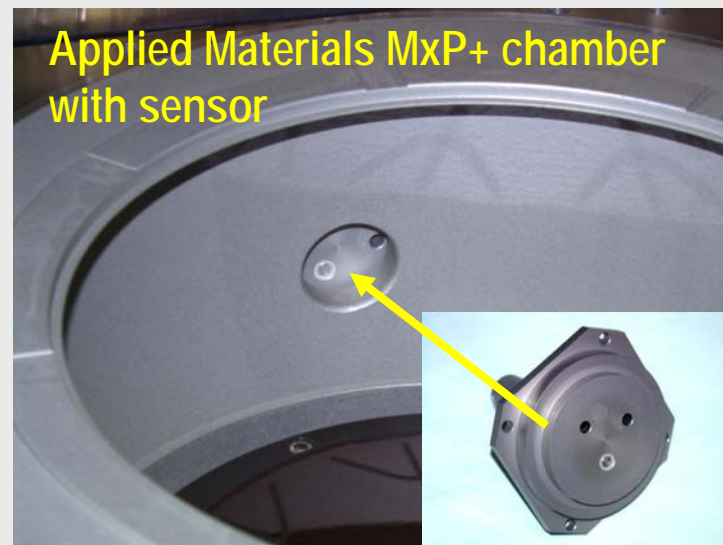
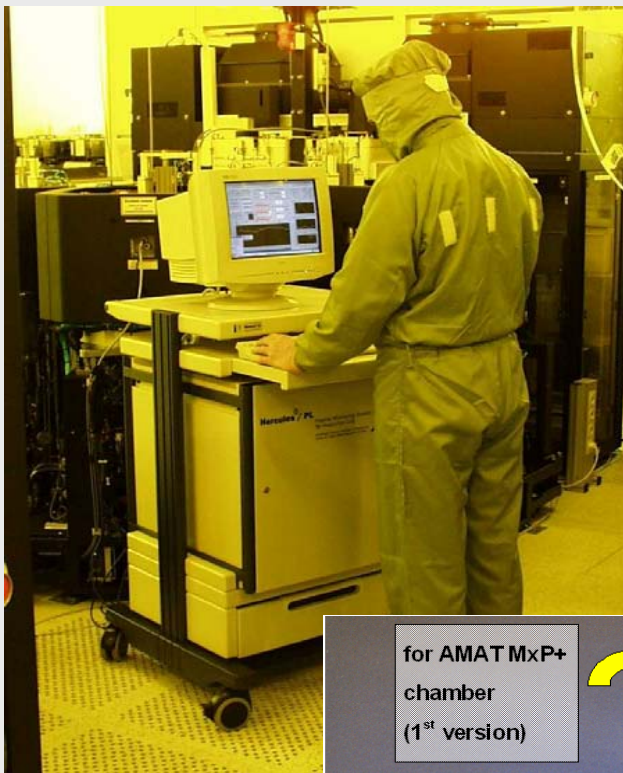
*Electron collision rate:*

$$\tilde{\nu} = \frac{\tilde{n}}{V} \int \frac{\nu}{n} dV$$

*Bulk power:*

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

# HERCULES Equipment Setup



Sensor surface: anodized aluminum, similar to chamber wall.

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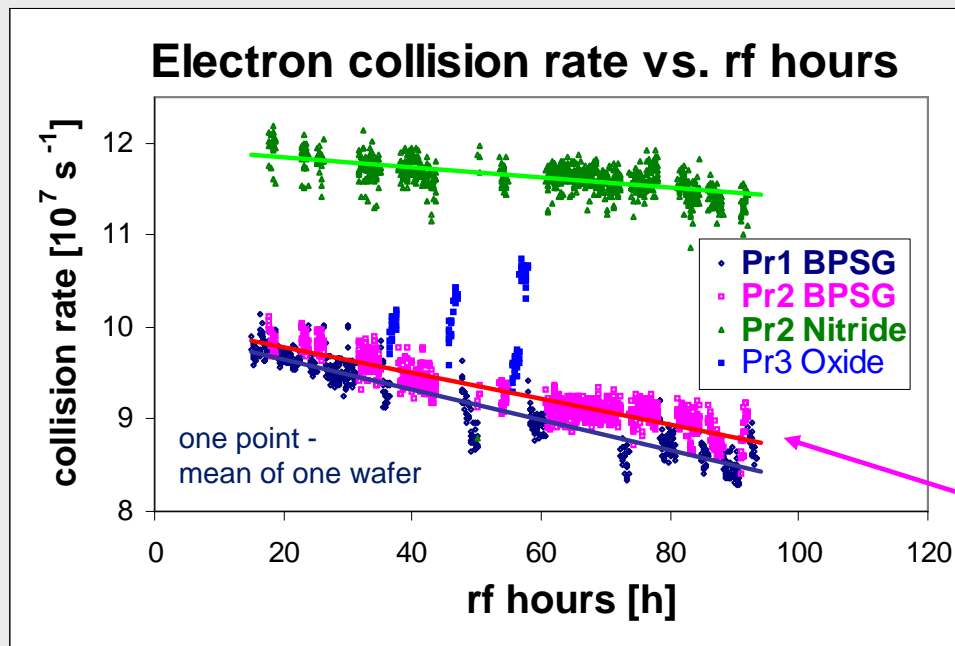


# Three examples of long term process monitoring

- 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 <sub>2</sub> / O <sub>2</sub> step
main	BPSG etch	BPSG etch
over	--	Nitride etch

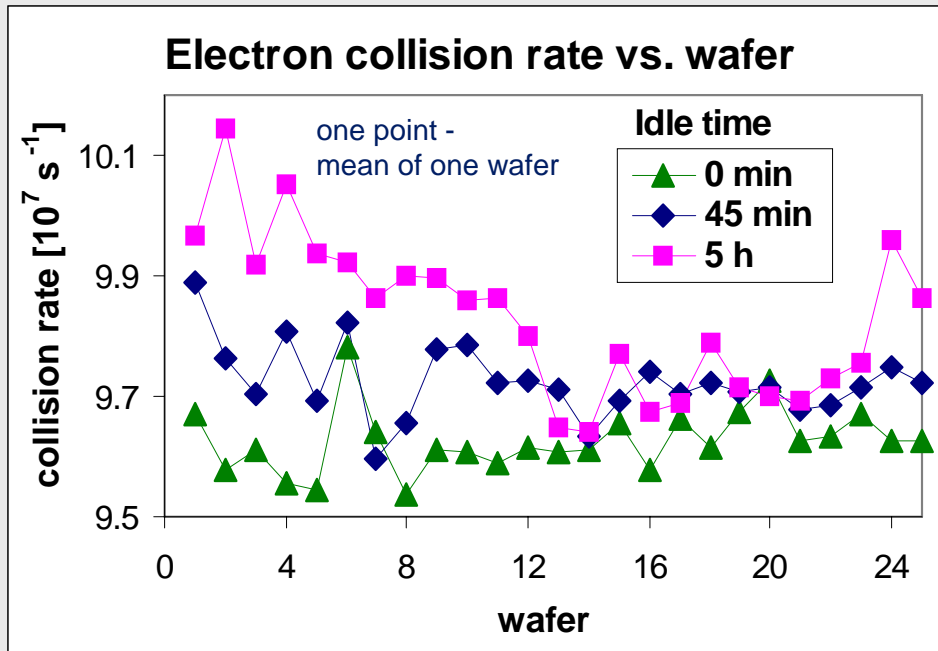
**Process 2:**  
deconditioning caused by pre step and over step.

Electron collision rate is very sensitive to etch chemistry.

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



# Short term chamber drift and first wafer effect

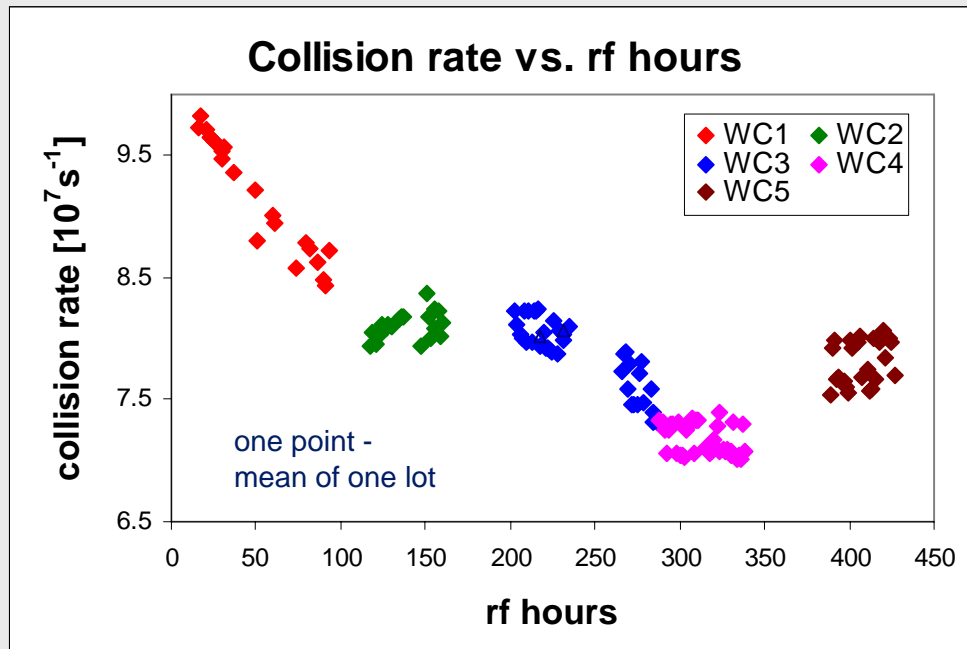


Contact etch at AMAT MxP+  
 Process monitoring of 3 lots of one product.

- 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.



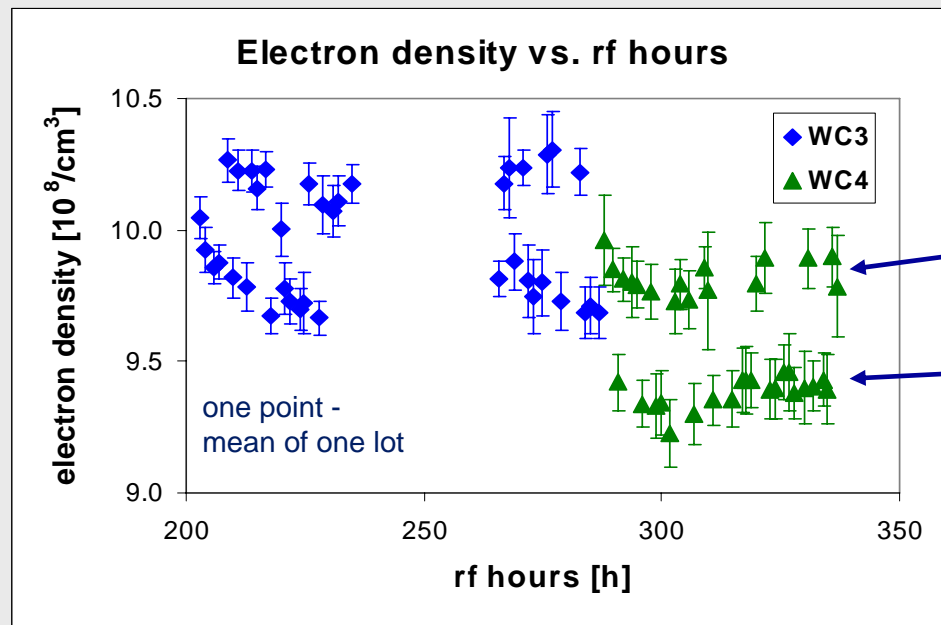
# Tool related effects on long term process stability



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

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

# 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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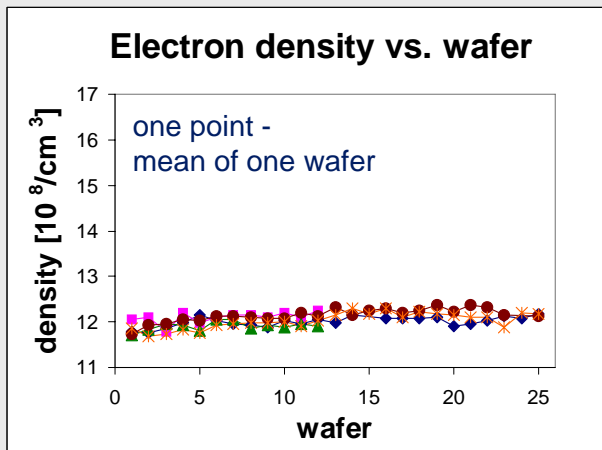


# Summary of the 1<sup>st</sup> process monitoring example

- 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 !



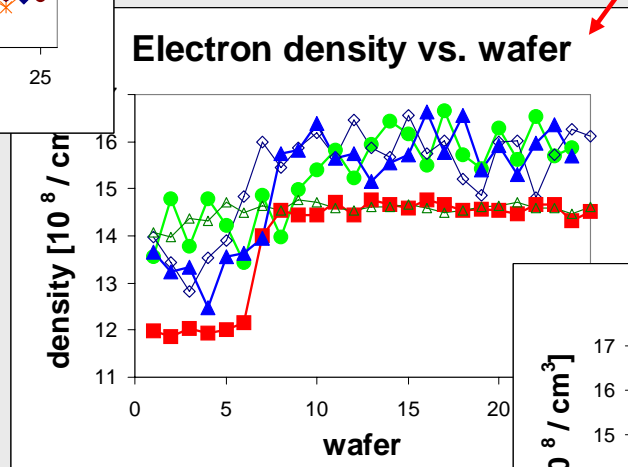
# Single wafer control of process stability



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

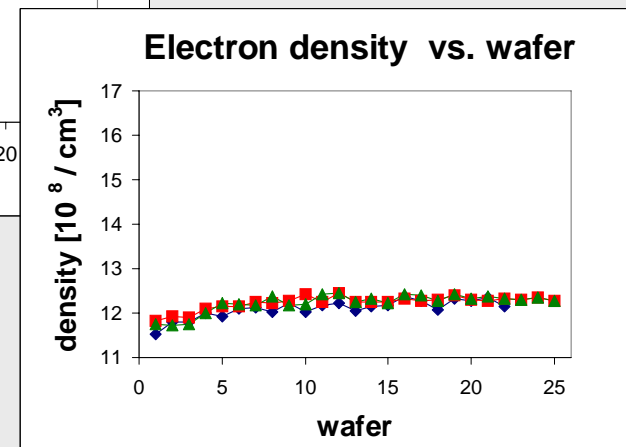
Sometime in 1998:  
Process o.k.

3 months later:  
Process problem !

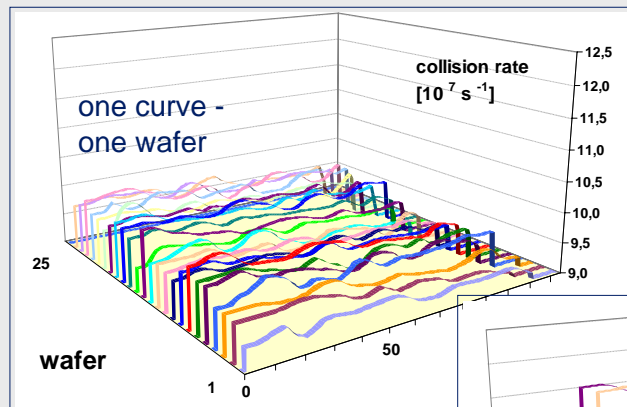


6 months later:  
Process o.k. again

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



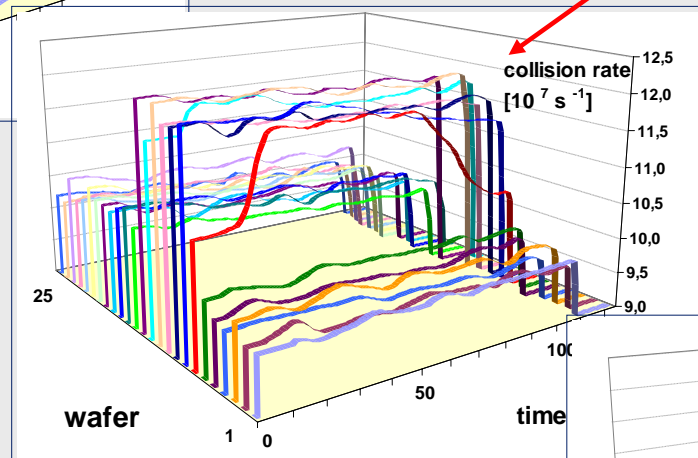
# Time resolved results of single wafer control



Sometime:  
Process o.k.

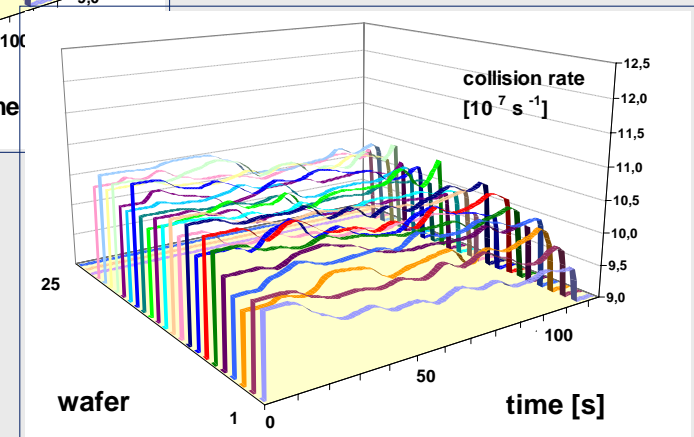
3 months later:  
Process problem !

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

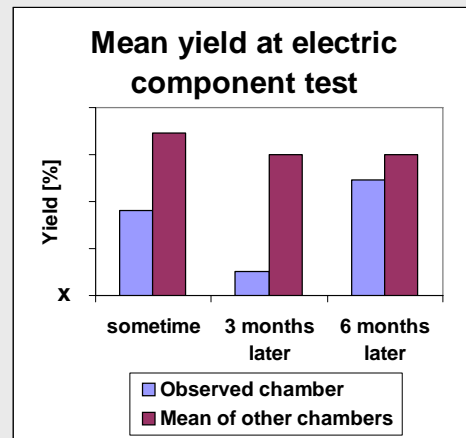
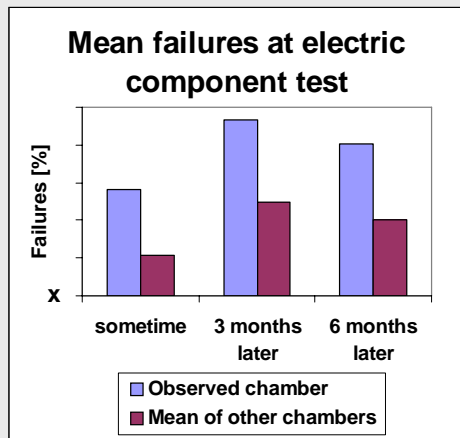
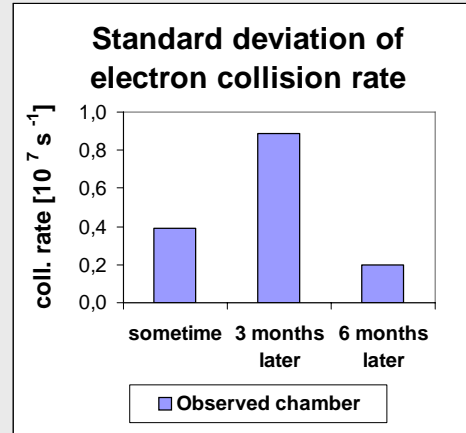
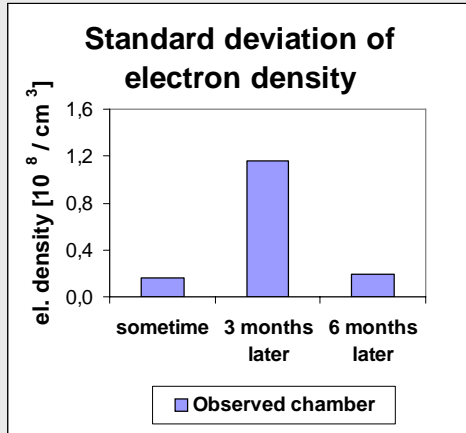


6 months later:  
Process o.k. again

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



# 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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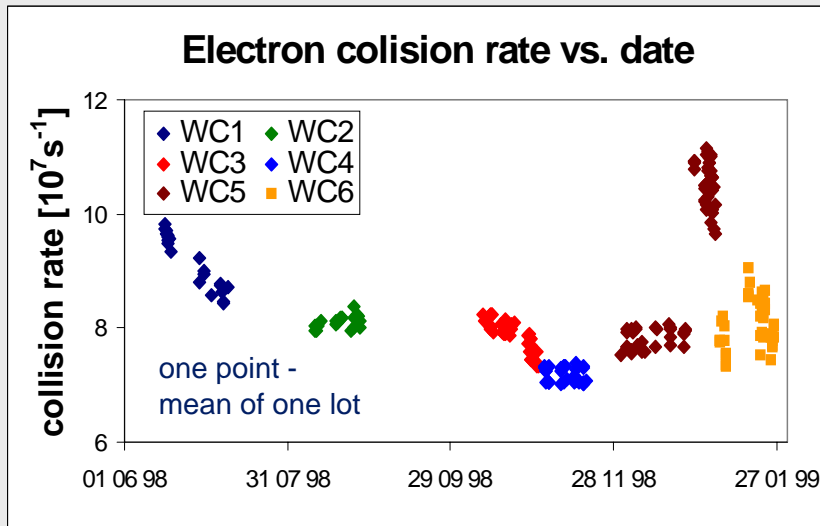


# Summary of the 2<sup>nd</sup> process monitoring example

- 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.



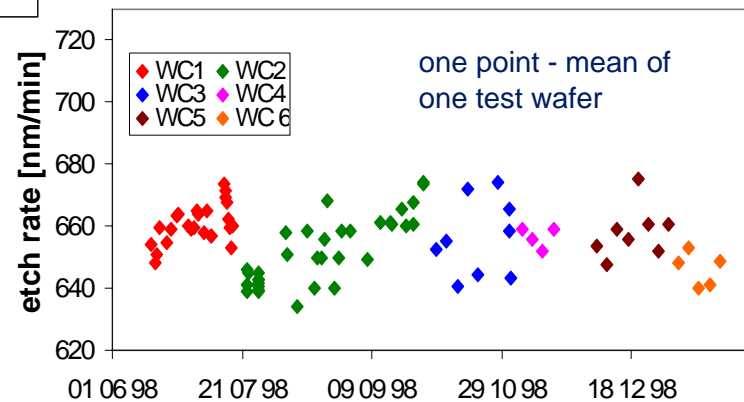
# Real time detection of hardware failure



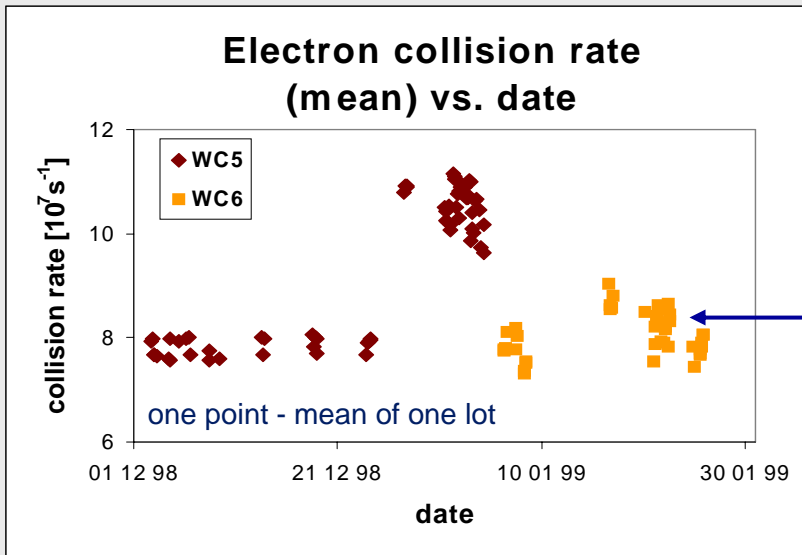
Increase of mean values of plasma parameters on all products indicate a hardware failure at the chamber.

Contact etch at AMAT MxP+

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

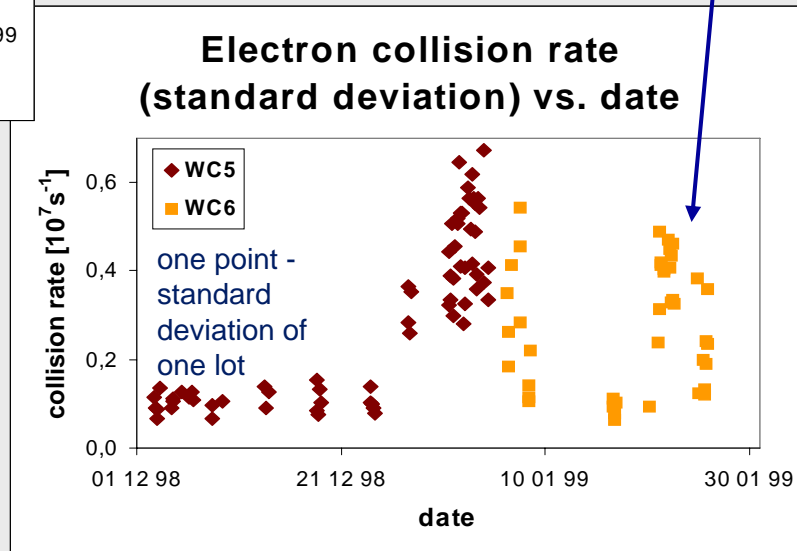


# Comparison between mean and standard deviation of plasma parameters

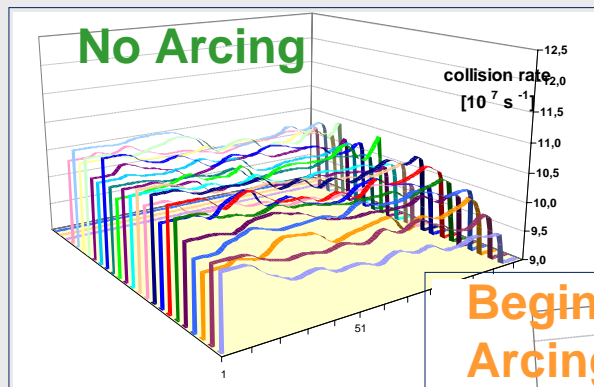


Standard deviation shows higher sensitivity to process instability.

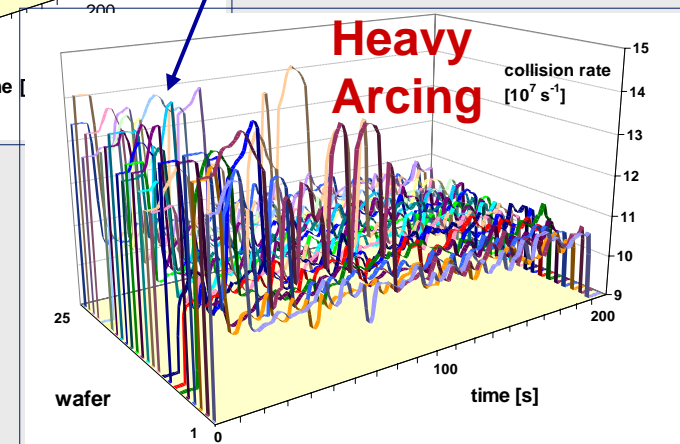
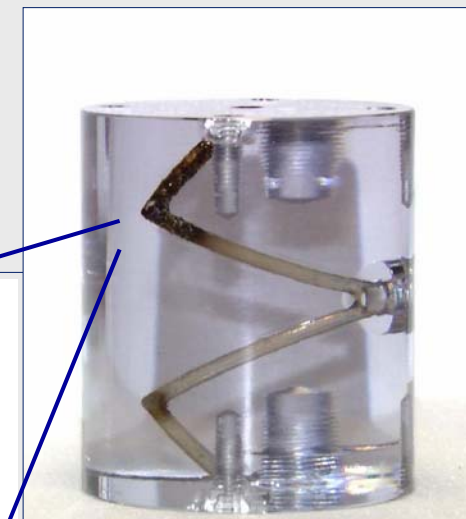
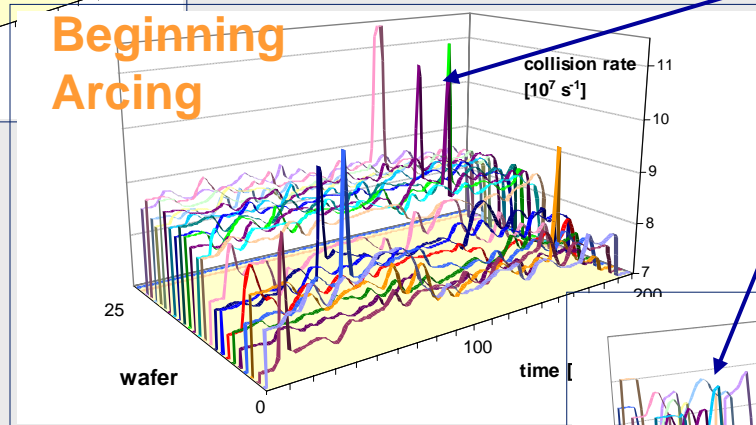
Contact etch at AMAT MxP+



# 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.



# Summary of the 3<sup>rd</sup> 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.

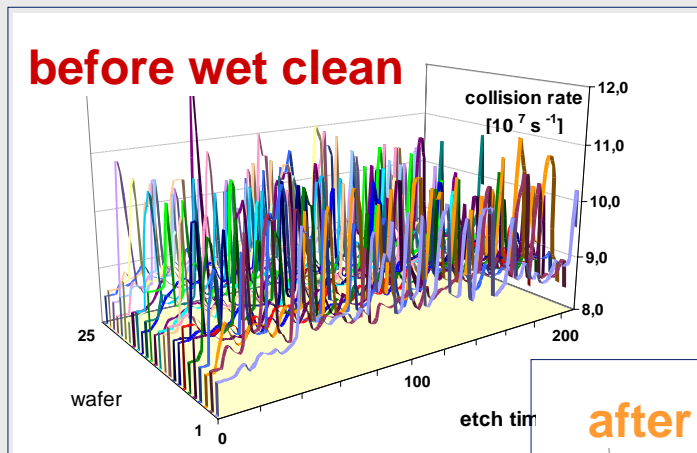


# Engineering applications

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

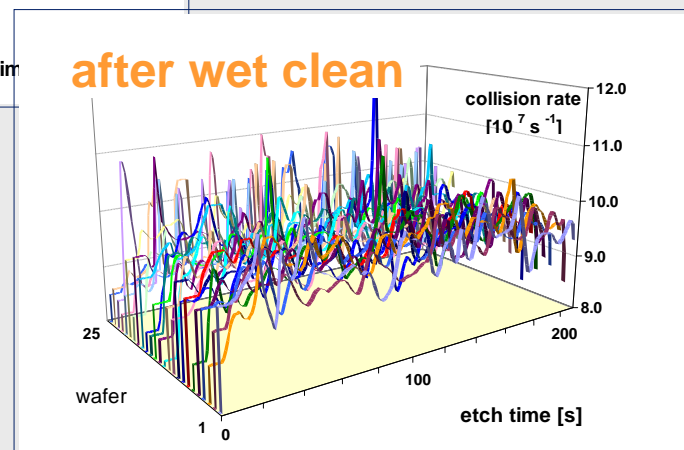
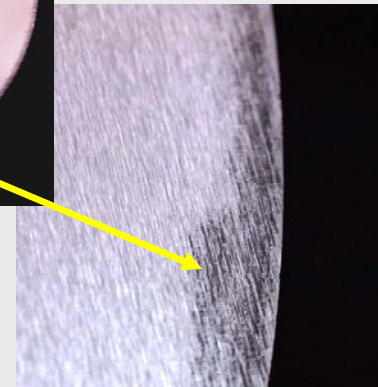
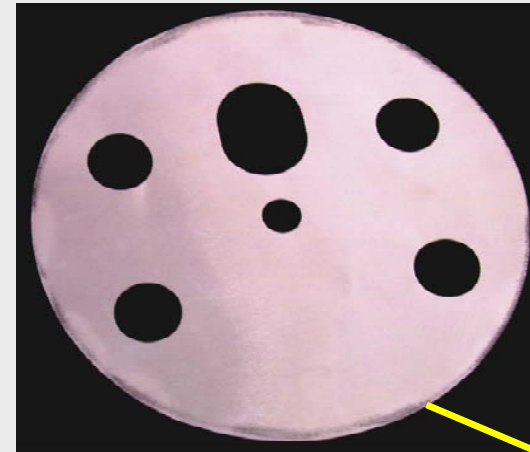


# Monitoring of maintenance activities - Example: Arcing detection at AMAT MxP+



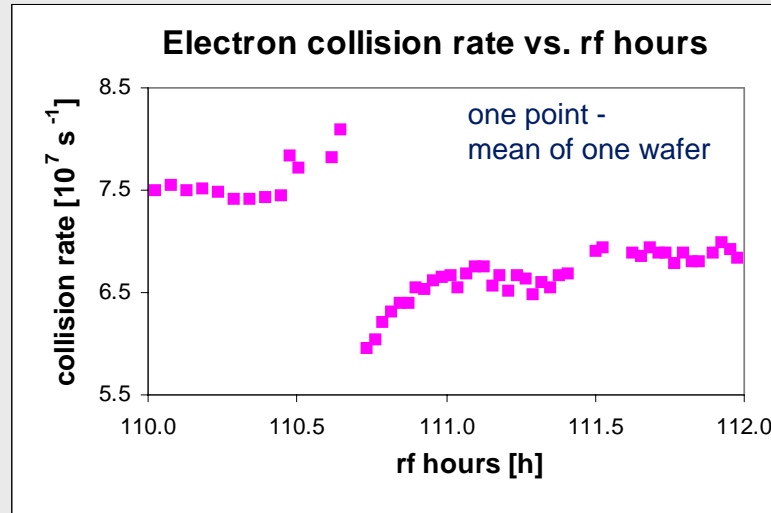
Contact etch at  
AMAT MxP+

Arcing below electro-  
static chuck at Al foil.



Arcing problem  
was not fixed  
by wetclean.

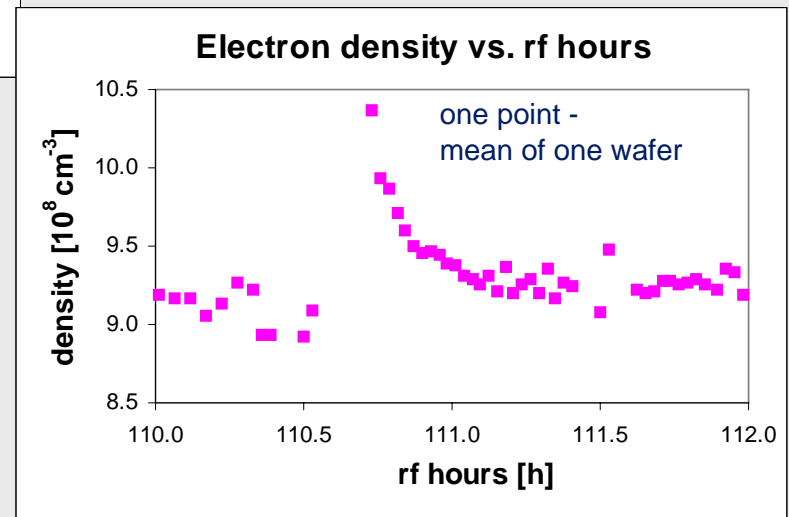
# Optimisation of conditioning after wet clean



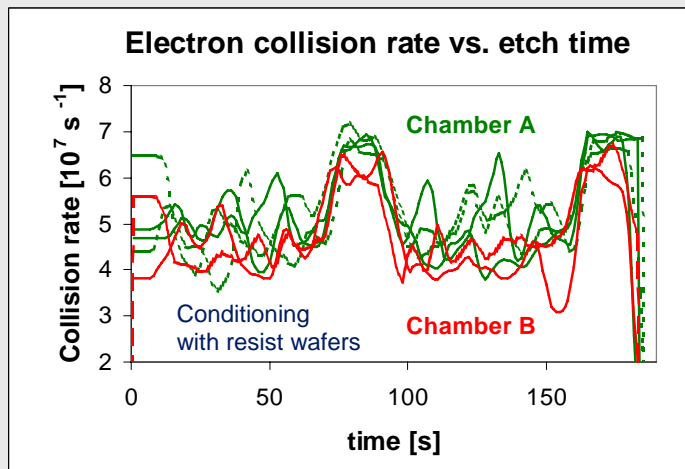
- Effect of chamber clean shows up in the electron collision rate.
- About 10 wafers are necessary to reach stable chamber conditions again.

Contact etch at AMAT MxP+

- Optimization of conditioning procedures → Non - Productive Wafer reduction

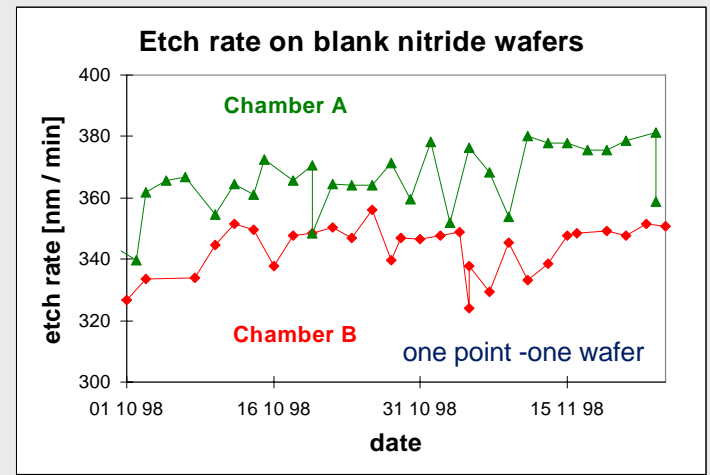


# Tool and chamber comparison by power density measurement



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.

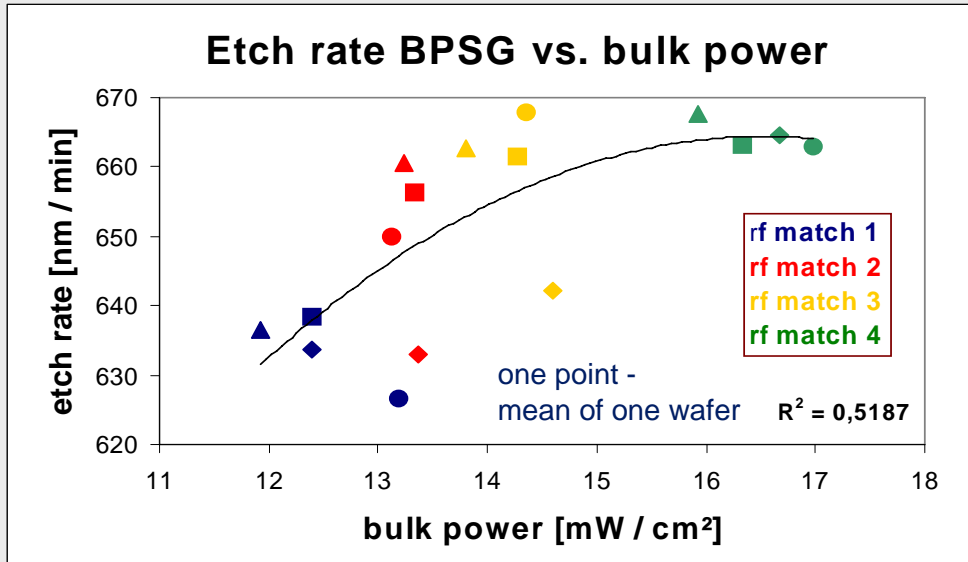


Nitride etch at AMAT MxP

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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.



- 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

