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Application of plasma parameters to Advanced Process Control

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Outline

- Plasma parameters – a new window for plasma process monitoring
- SEERS at Infineon – short story
- SEERS evaluation and application at Infineon Dresden 200 mm
  - 1st step: Basic evaluations and experiments
  - 2nd step: Basic demo applications
  - 3rd step: Production relevant applications
- Plasma parameters fit the concept of **A**dvanced **P**rocess **C**ontrol

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Established and new measurement techniques – a historical comparison

- Optical methods in astronomy
  - Have been used for many hundred years now
  - They are familiar to every astronomist
  - Very useful, great results
  - But they use only a small wavelength window
- In the 20th century new methods appeared
  - Measuring in other regions of the electromagnetic spectra
  - Examples are Ultraviolett and Infrared, Röntgen and **Radio astronomy**

- Optical methods in industrial plasma processing
  - Are widely used, e.g., OES and interferometry
  - They are familiar to every engineer
  - Standard methods, endpoint
  - But they use only a small wavelength window
- During recent years new methods appeared
  - Measuring in other regions of the electromagnetic spectra
  - One of these new upcoming methods, using Radio frequencies, is **SEERS**

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Plasma parameter measurement – a new window for plasma monitoring in production

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- New plasma monitoring techniques, SEERS is an example
  - Don´t replace the established ones
  - Are used as a supplement
  - Offer additional abilities for process control
- SEERS measures plasma excitation parameters
  - Electron collision rate: How often does such a poor electron collide with molecules, atoms in the plasma bulk.
  - Electron density: How many free electrons are there in the plasma bulk per volume unit.
  - Bulk Power: The power, dissipated by inelastic collisions of the electrons, the most important plasma excitation process.
  - DC Bias Voltage: The mean difference of the dark space voltages at the cathode and the grounded chamber wall.
- RF plasma is a non equilibrium plasma, driven by electron collisions ➔ these plasma excitation parameters are well suited to characterize plasma process conditions.

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Why didn´t we use plasma parameters for process control in production formerly ?

- Plasma parameters can be measured by other methods too, e.g. Langmuir probes.
- But they can not be used in production, because of
  - Impacts on the process:
    - Active measurements, e.g. voltage application
    - Disturbance of geometry
    - Particles !
  - Fundamental problems in production enviroment
    - Polymers on Langmuir probe surface !
- SEERS measurement technique overcomes fundamental problems:
  - Passive method, no voltage applied
  - Flat sensor at the chamber wall on ground potential
  - RF current measurement ➔ not sensitive against polymer on sensor surface
- SEERS is the first technique to measure plasma parameters in production

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SEERS evaluation and application at Infineon – an upcoming plasma monitoring method

Regensburg:	1997
München:	1998
Dresden 200 mm Fab:	1998
Dresden 300 mm Fab:	1999
Essonnes:	1999
Fishkill:	2000

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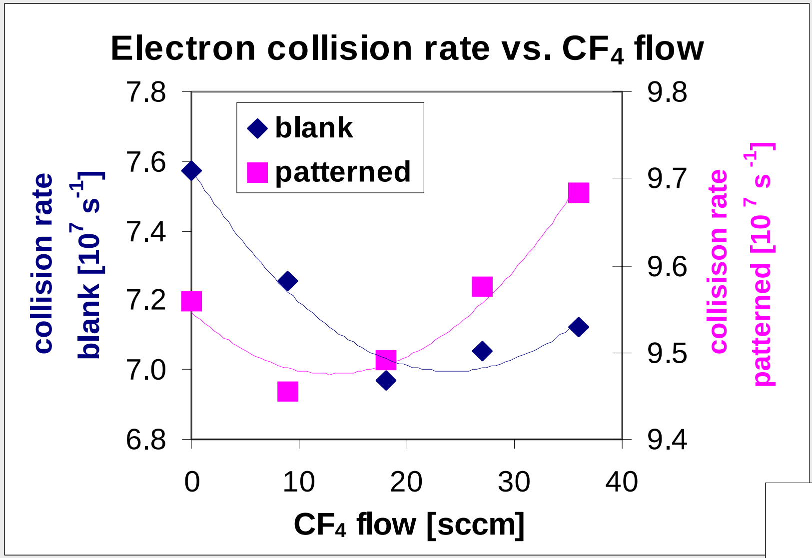
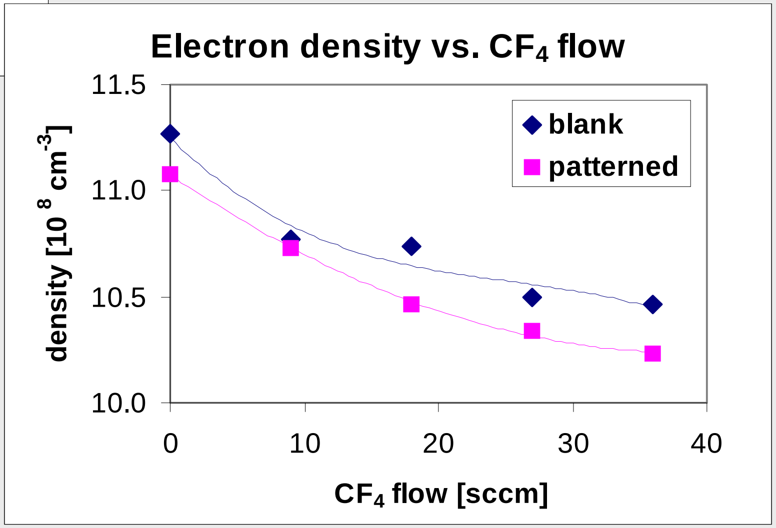
SEERS at Infineon Dresden 200 mm Fab
1st step: Basic evaluations and experiments

- Does this new measurement equipment work reliable (new hardware, new software) ?
- Are these new, still unknown plasma parameters sensitive to known tool- and process parameters ?

Example: Process parameter variation at Contact etch in AMAT MxP+ chamber



- Variation of CF_4 flow in a CF_4 / CHF_3 / Ar gas mixture shows strong nonlinear impacts on electron collision rate and electron density



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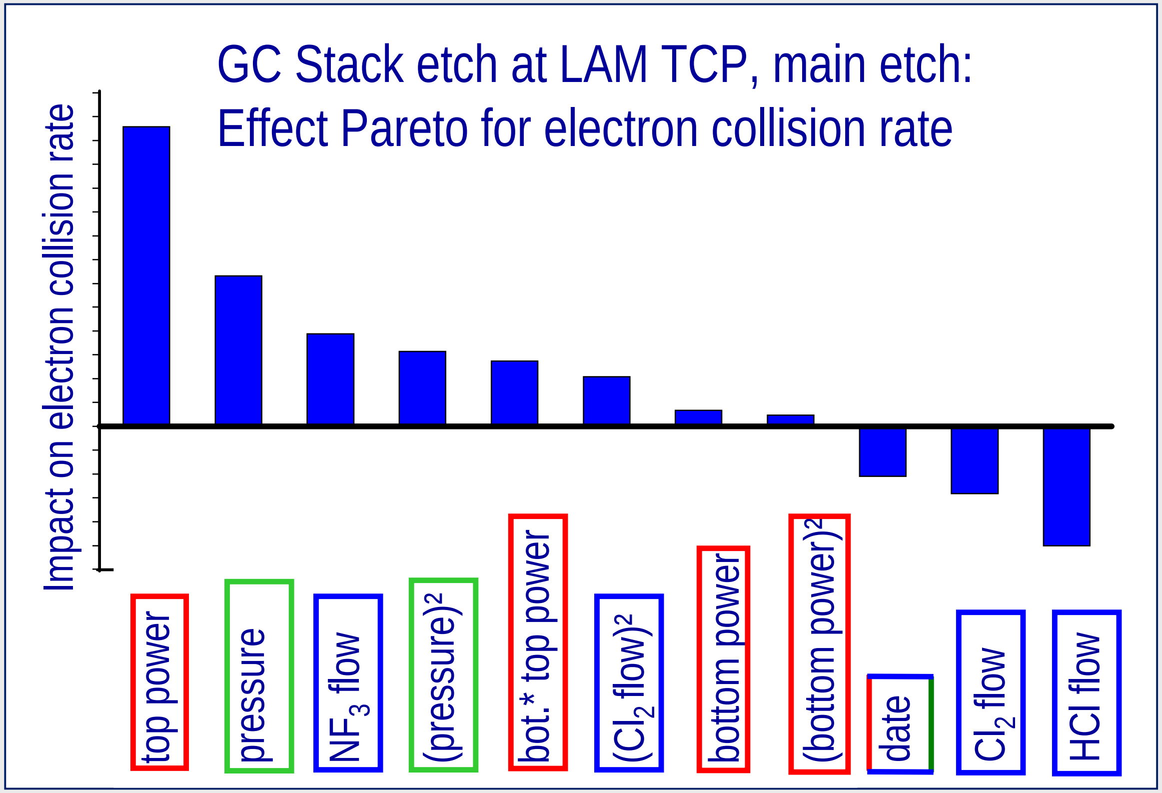
Example: Process parameter variation at GC stack etch in LAM TCP



$$\nu = \sqrt{\frac{8\boxed{kT_e}}{\pi m_e}}\;\boxed{\frac{p}{kT_N}}\sum_k \boxed{\frac{p_k}{p}\sigma_k}$$

- Electron collision rate depends on parameters, which can be measured
- Electron collision rate depends also on parameters, which can not be measured (chamber drift = impact of date)

Conclusions from basic experiments

- Plasma parameters are very sensitive on impacts
  - Which we know and we can measure reliable, e.g.:
    - Pressure
    - gas flows
  - Which we know and we can not measure reliable, e.g.:
    - RF power input into the chamber
  - Which we don´t know and we can not measure at production tools generally:
    - Surface conditions on the wafer and at the chamber wall
    - Physical effects and complex chemical reactions in the plasma
- A plasma parameters is a complex process parameter
  - Integrating impacts of many effects in one value
  - For practical use this complexity is an advantage and a disadvantage at the same time.

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SEERS at Infineon Dresden 200 mm Fab
2nd step: Demo applications

- Well, these plasma parameters are really sensitive to many impacts.
- Let´s see, how we can use them !

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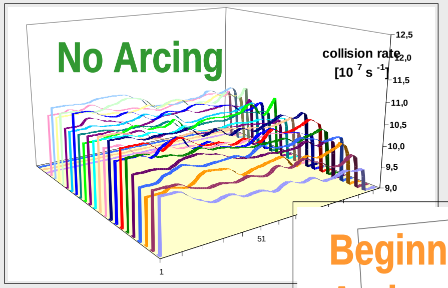
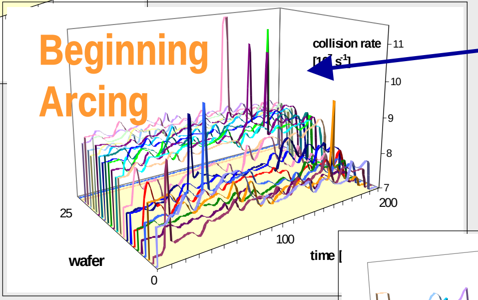
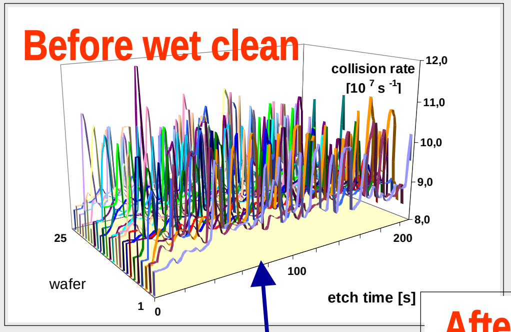
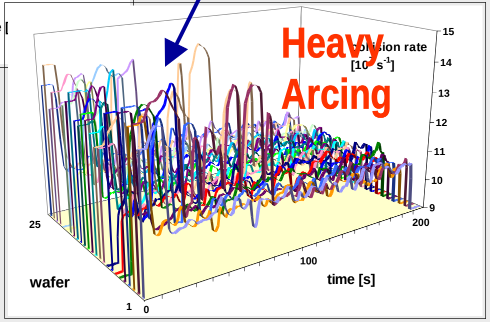
Arcing detection at AMAT MxP+ chamber by measurement of electron collision rate

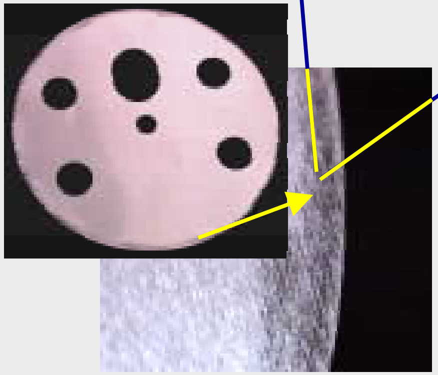
Plasma parameter used for real time in-situ arcing detection

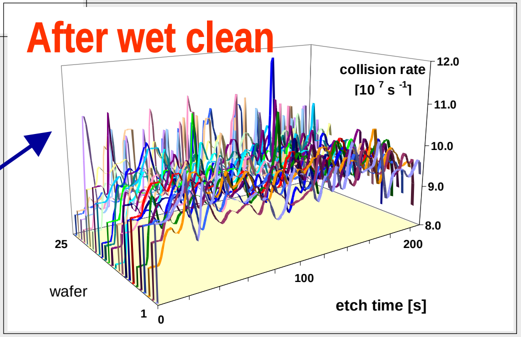












The wet clean was not successful, arcing detected before and after wet clean

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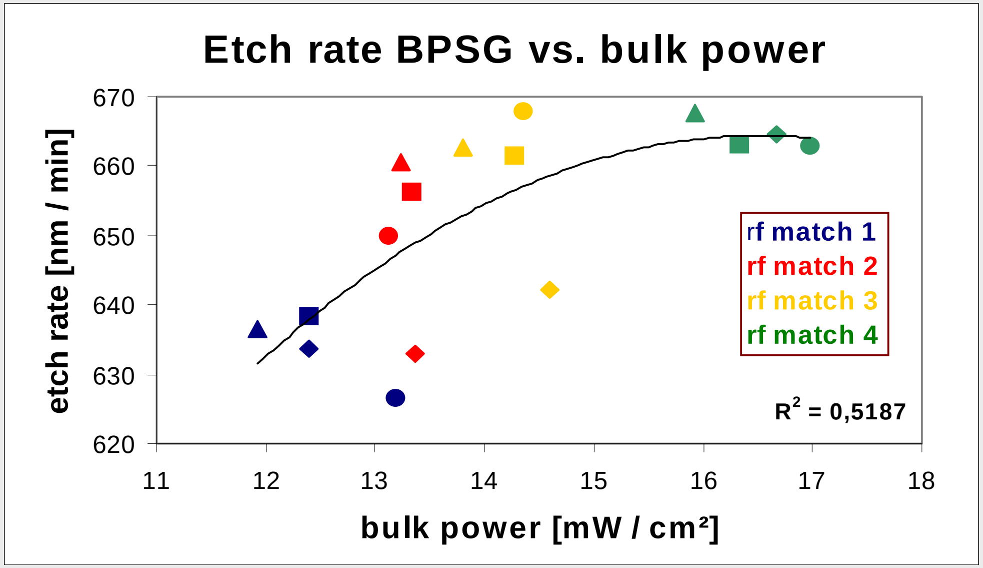
Power efficiency comparison of 2nd source RF match boxes at AMAT MxP+ chamber by bulk power



Task: Comparison of RF matchbox efficiency by measurement of bulk power dissipation inside the chamber (nominal RF generator power output is kept constant)

- Power coupling into the chamber differs about 25 ... 30% as indicated by bulk power.
- Drift of chamber conditions during the experiments is obvious.
- Oxide etch rate saturation at high power dissipation (RF match 4) is possibly caused by transport processes or surface reactions.

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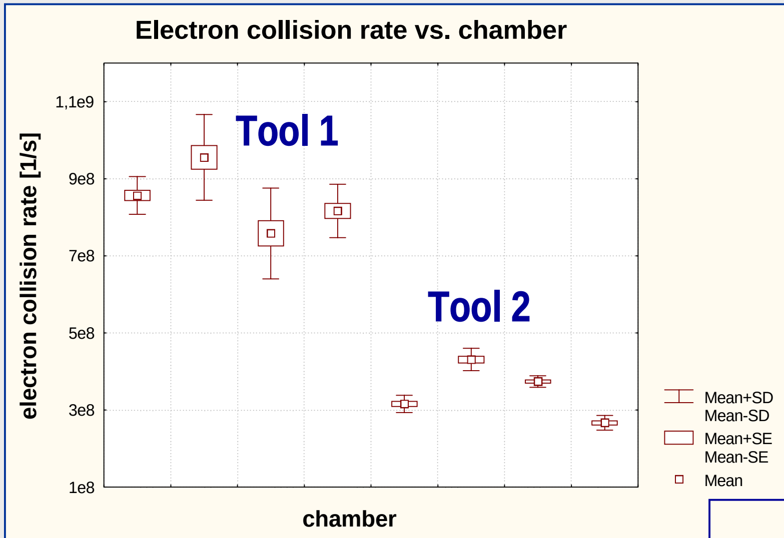
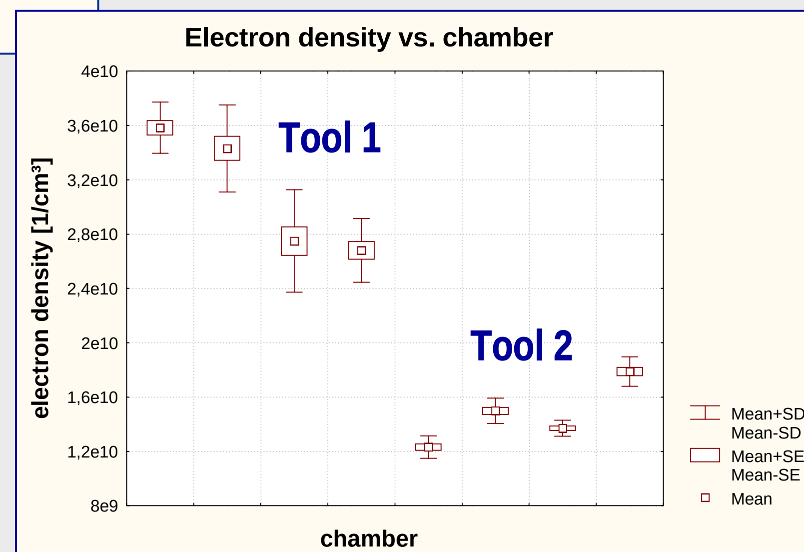
Tool comparison at Metal etch in LAM TCP indicates RF power related problem at one chamber



- Two LAM TCP with „nominal similar“ parameters showed significant different etch results
- 4 production lots were splitted to compare both chambers

- Plasma parameters, measured on production lots, indicate significant difference of power dissipation in both chambers.
- Therefore maintenance measures were concentrated on RF related problems.



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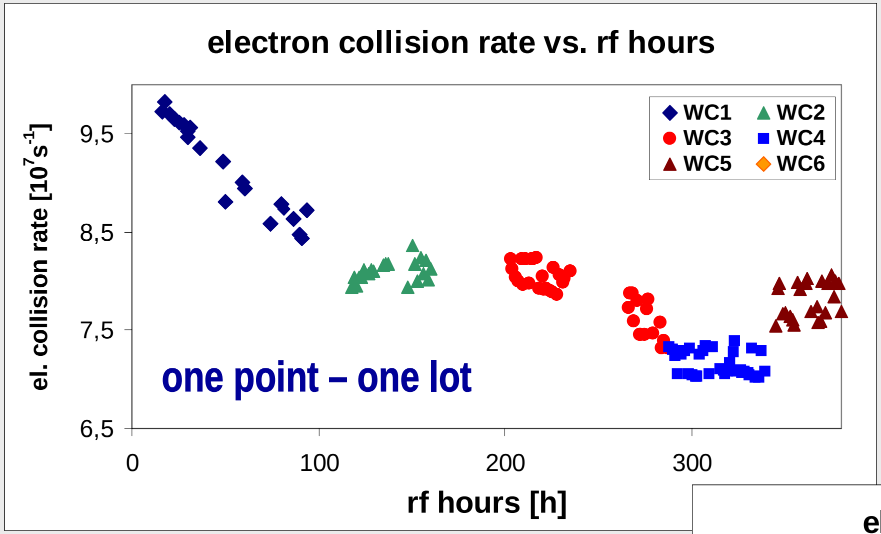
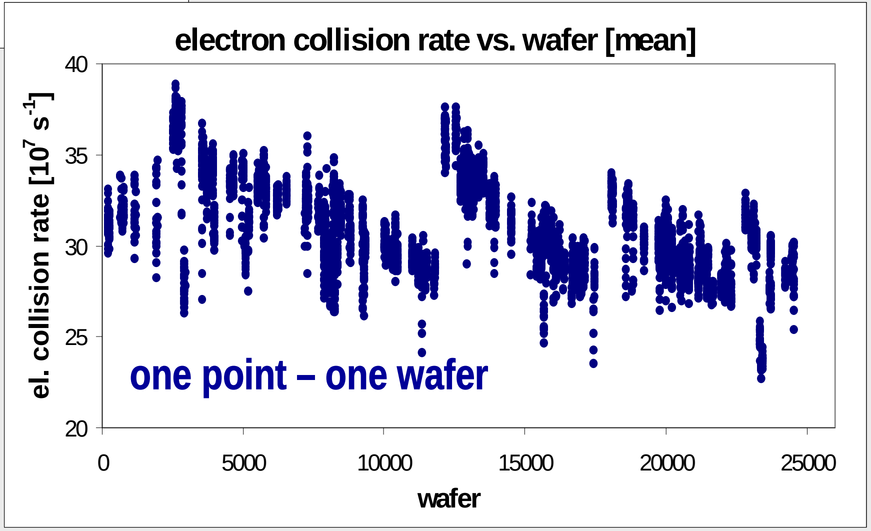
Comparison of wet clean reproducability at AMAT MxP+ and LAM TCP



- Contact etch at AMAT MxP+ chamber, one recipe
- Electron collision rate indicates significant wet clean impact on process



- GC Stack etch at LAM TCP, main etch, one recipe
- „Jig saw like“ chamber drift
- Wet clean impact on process more reproducable

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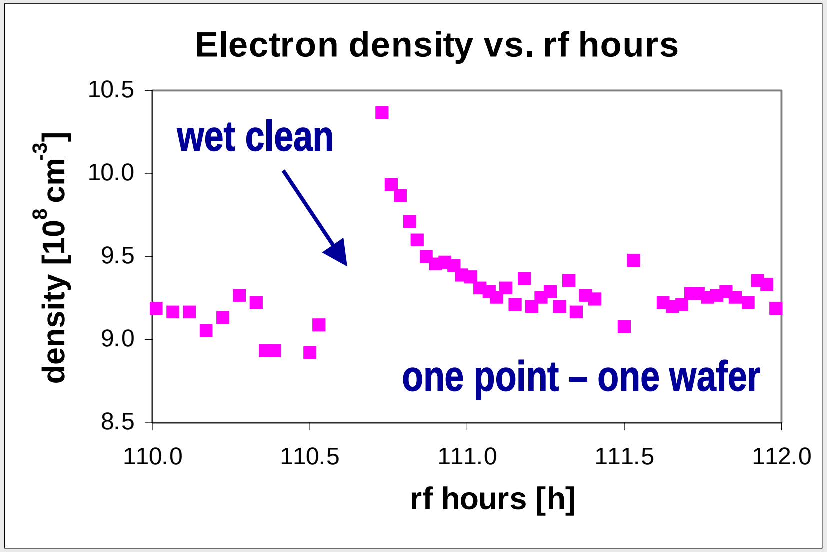
Optimization of conditioning procedure after wet clean at Contact etch in AMAT MxP+



- Contact etch at AMAT MxP+, conditioning after wet clean using resist wafers
- Electron density indicates chamber drift after wet clean

- Plasma parameters can be used to monitore the effect of clean and conditioning procedures in real time
- Benefit:
  - Easy to use, „quick and dirty“ method for clean and conditioning optimization
  - Results are available immediately

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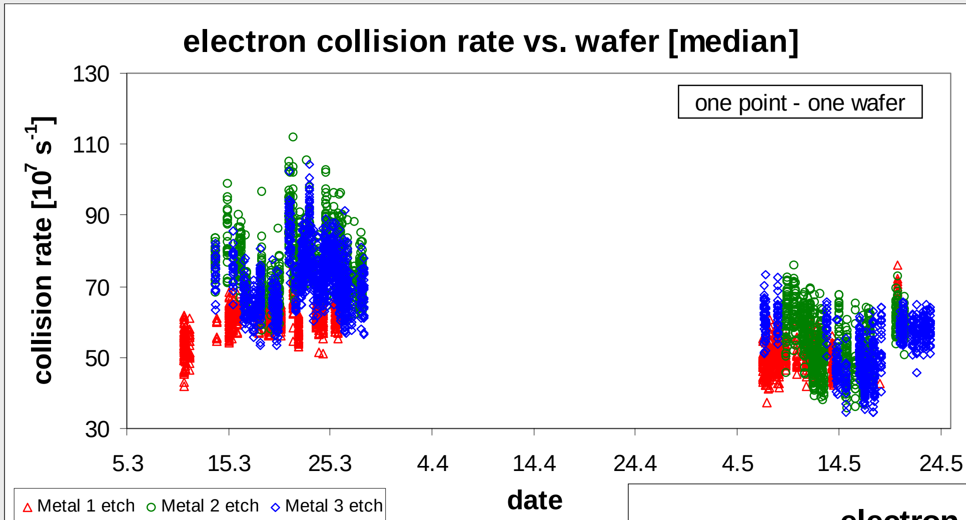
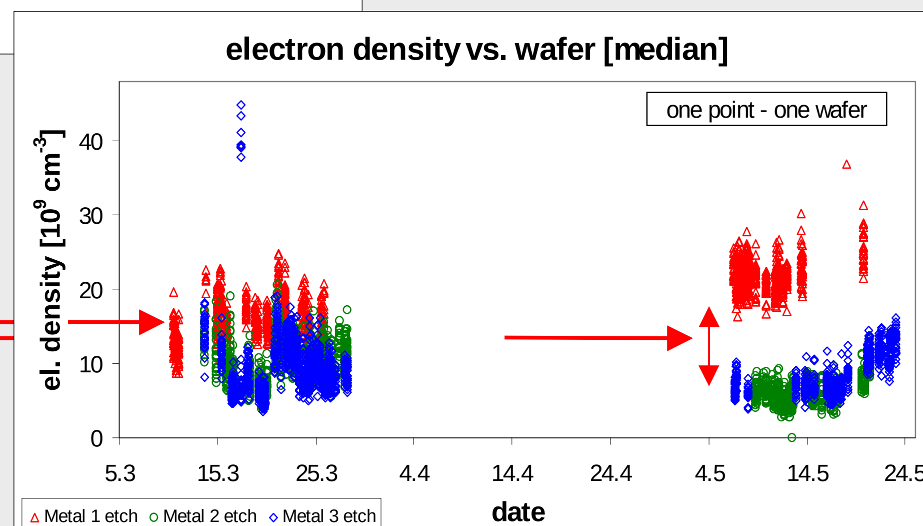
Measurement of wet clean impact and long term process drift at Metal etch in LAM TCP



- Plasma parameter measurement at three metal etch processes in one LAM TCP chamber
- Process drift between wet cleans is visible

- Electron density indicates significant process change at Metal 1 etch (compare March and May)



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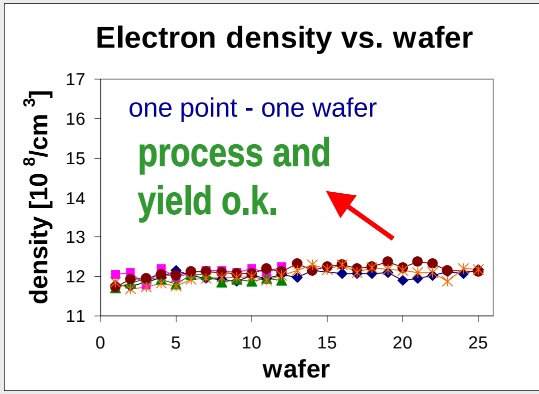
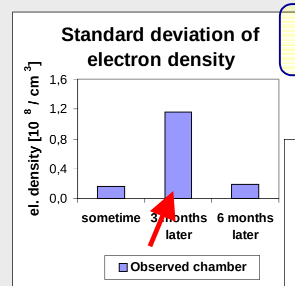
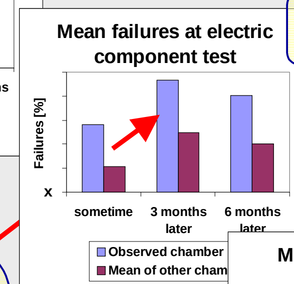
Yield problem at DRAM product detected by electron density measurement in real time



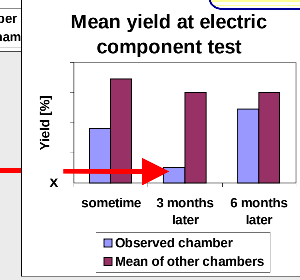


Electron density ↑

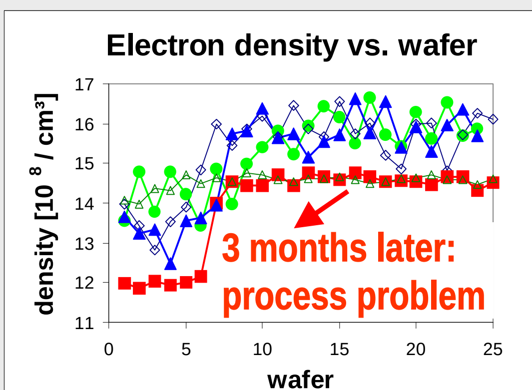


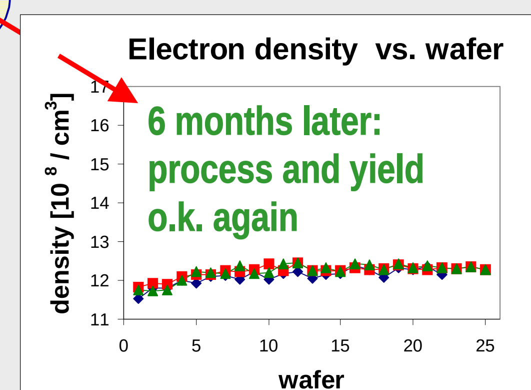
Failure ↑

Yield ↓

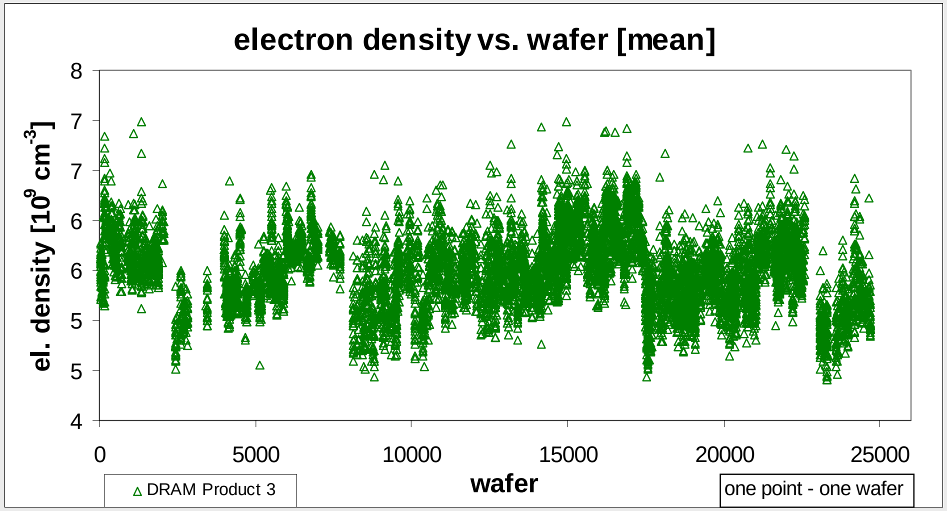


Electron density detects yield relevant process problem of CT etch pre- process in real time.



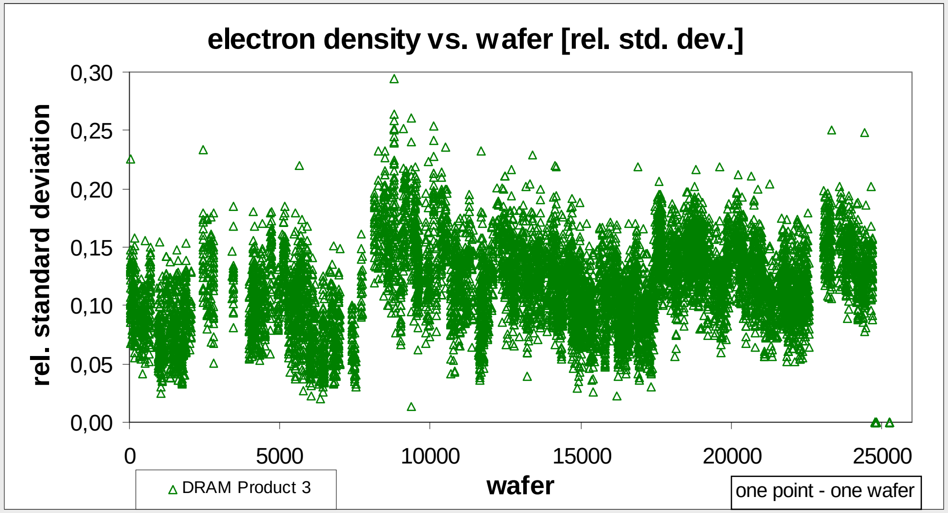


Gate stack main etch at LAM TCP: Wet clean impact on chamber conditions measured by electron density



Mean value of electron density indicates chamber drift between wetcleans.

Relative standard deviation of electron density shows higher process stability with increasing rf hours slightly.



Conclusion:

Chamber drift over wet clean cycle is in the same order of wafer to wafer range ➔ Stable process conditions at that etch step of this product in this chamber.

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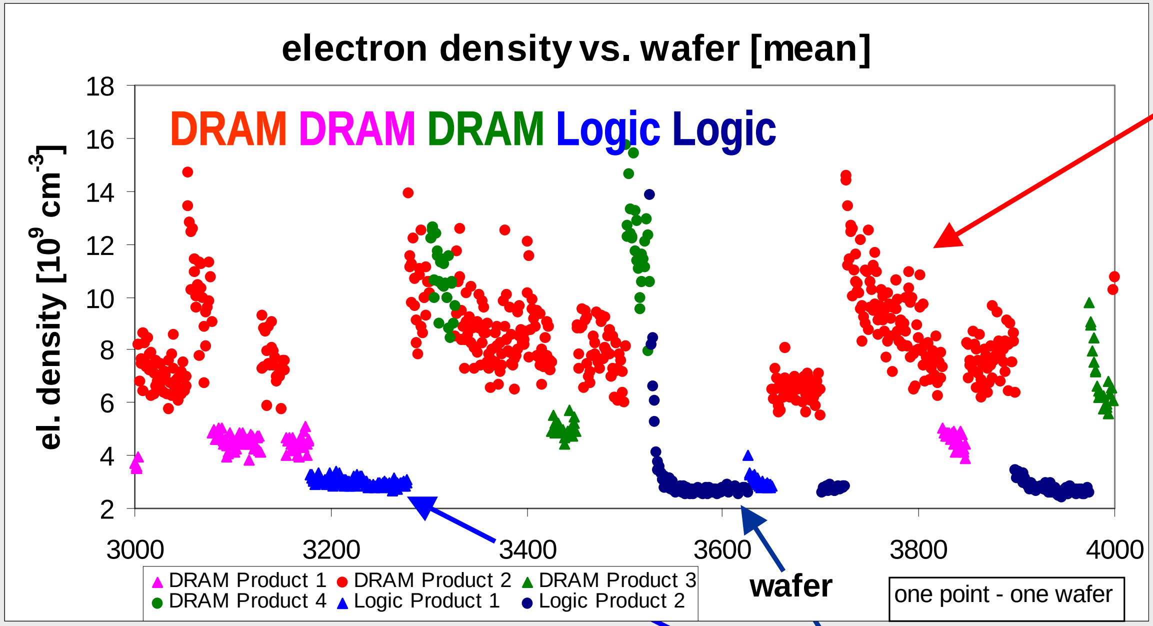
2nd Workshop on Self Excited Electron Plasma Resonance Spectroscopy
11th – 12th of December 2000, Dresden - Germany

Process stability wafer to wafer at GC Stack etch in LAM TCP, over etch, indicated by electron density



- DRAM products show large wafer to wafer mean variation

- Mean value of electron density at GC Stack over etch show product depending wafer to wafer process stability
- Possible reason: pre-process

- Logic Products shows high wafer to wafer process stability

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Impact of process mix on chamber conditioning at GC Stack etch in LAM TCP, over etch

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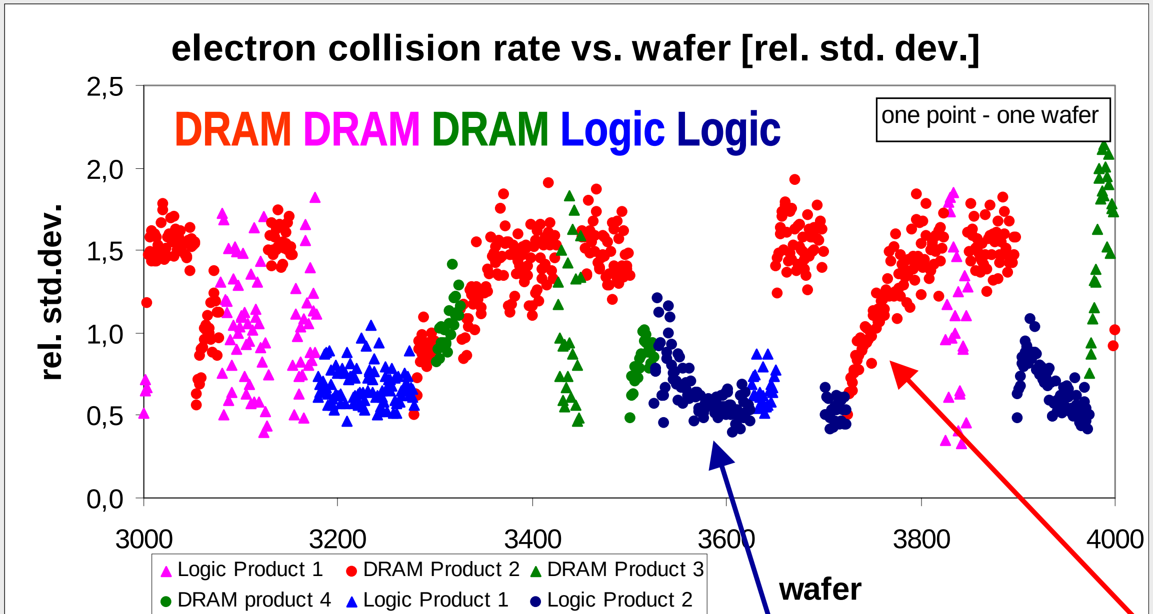

- Relative standard deviation of electron collision rate at GC Stack over etch indicates impact of DRAM and Logic products on chamber conditioning
- Logic Products stabilize chamber conditions
- DRAM products destabilize chamber conditions

Conclusions from demo applications

- Demo applications demonstrate the use of plasma parameter measurement for
  - Tool related applications
    ➔ helpful for maintenance
  - Process related applications
    ➔ helpful for unit process mastering
    ➔ helpful for process integration and product engineering
- Demo applications demonstrate the benefit potential of plasma parameter measurements for Advanced Process Control
- Demo applications can not realize the full benefit potential because of problems in
  - Sensor and tool integration
  - Autmatical data handling

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SEERS at Infineon Dresden 200 mm Fab

3rd step: Production relevant applications

- Well, these demo applications look promising. Why didn´t we use this measurement technique really in production yet ???
- That´s a very good question !!!

Current application status of SEERS

- Demo applications show the benefit potential, but till now we did not achieve a real benefit, because of:
  - Lack of experience, which values of the parameters are „normal“ and „not normal“
  - We need process problems and hardware failures at least one time, to detect them later
  - The data handling was done „by hand“ mainly with a lot of efforts, to slow.
- We must correlate plasma parameters with tool data, other process data and product data. Therefore we need the necessary infra structure:
  - Reliable sensor and equipment integration
  - Data bases
  - Data analysis software (Excel on the desk is not enough)
  - Real time alarm in case of a detected problem
- The 3rd step we start right now. See the following presentations !

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Use of plasma parameters for data reduction at **A**dvanced **P**rocess **C**ontrol in high volume production

- Application of **A**dvanced **P**rocess **C**ontrol in high volume production creates very large amounts of data ➔
- Data reduction as much as possible, otherwise we have no chance !
- How to solve the data reduction problem:
  - Collect process data and tool data
  - Reduce the data amount by calculation of statistical key numbers
  - Store all statistical key numbers in data base
  - Use one (or few) complex process parameters for daily process monitoring
  - Use other process and tool parameters to fix process and tool problems in detail

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Application of plasma parameters for **F**ault **D**etection and **C**lassification

- Complex process parameters depend on tool **and** wafer ímpacts.
- As long key numbers of complex process parameters are constant, we can (nearly) be sure, that the process runs well, tool **and** wafer are in good conditions.
- If a key number of a complex process parameter is out of spec, either tool, or wafer or both are out of spec. In this case
  - Check the tool by use of tool data key numbers
  - Check the wafers by use of wafer relevant key numbers
- This is a way for data reduction at APC in high volume produciton:
  - 1st step: The complex key parameter indicates, that something might be wrong
  - 2nd step: The other key parameters and measurements help to find, what is wrong in detail.
- Plasma parameters are an example of such complex key parameters.

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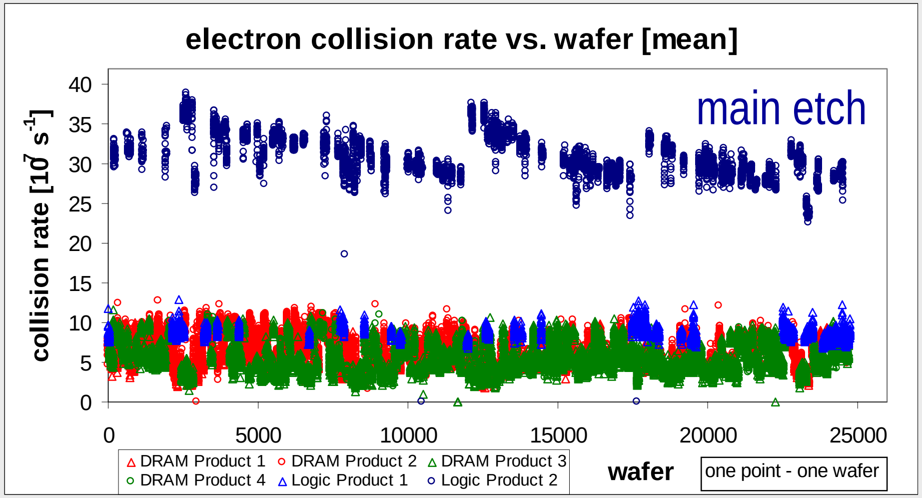
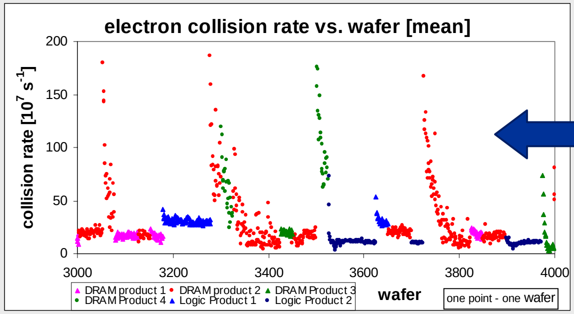
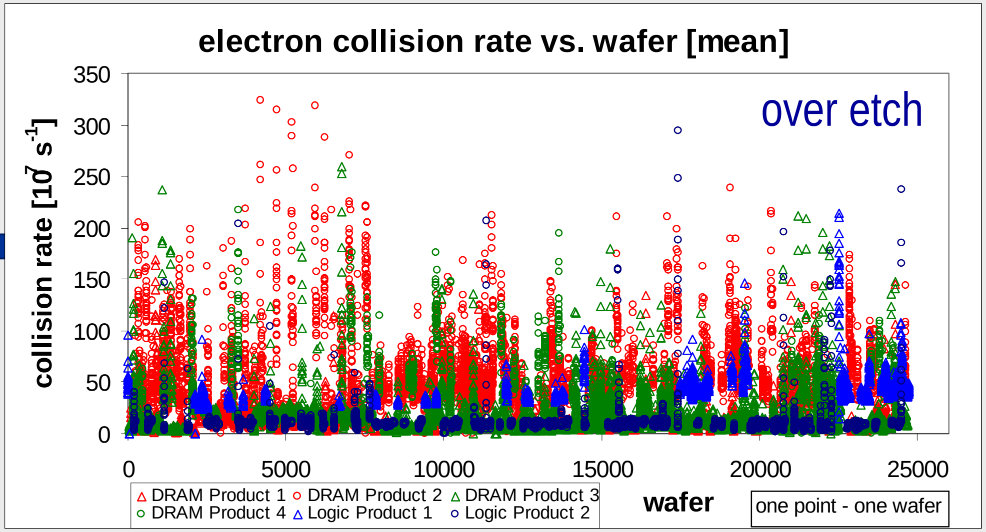
GC stack etch at LAM TCP: Comparison of main etch and over etch by electron collision rate



- Process parameter measurement separately necessary for:
  - Etch steps and
  - Products





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Summary

- SEERS has been used for plasma parameter measurement at Infineon Dresden for nearly three years now.
- Basic experiments showed, that plasma parameters indicate tool and wafer impacts on the process.
- Demo applications demonstrated the potential benefit for maintenance, unit process mastering, process integration and product engineering.
- To realize production relevant applications in real time, we have to overcome the infrastructure bottlenecks, e.g., sensor integration and data handling.
- Plasma parameter measurement is a helpful method to realize Advanced Process Control in high volume production.

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