Application of plasma parameters to Advanced Process Control

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Das diesem Bericht zugrundeliegende Vorhaben wurde mit Mitteln des Sächsischen Staatsministeriums für Wirtschaft und Arbeit (Förderkennzeichen 5706) gefördert.
Die Verantwortung für den Inhalt dieser Veröffentlichung liegt beim Autor

2nd Workshop on Self Excited Electron Plasma Resonance Spectroscopy
11th – 12th of December 2000, Dresden - Germany
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 Advanced Process Control
## Established and new measurement techniques – a historical comparison

<table>
<thead>
<tr>
<th>Optical methods in astronomy</th>
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<tbody>
<tr>
<td>Have been used for many hundred years now</td>
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<tr>
<td>They are familiar to every astronomer</td>
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<tr>
<td>Very useful, great results</td>
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<td>But they use only a small wavelength window</td>
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<th>In the 20th century new methods appeared</th>
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<td>Are widely used, e.g., OES and interferometry</td>
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<td>They are familiar to every engineer</td>
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<td>One of these new upcoming methods, using Radio frequencies, is SEERS</td>
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Plasma parameters – a new window
Plasma parameter measurement –
a new window for plasma monitoring in production

- 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.
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
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
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 CF₄ flow in a CF₄ / CHF₃ / Ar gas mixture shows strong nonlinear impacts on electron collision rate and electron density.

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

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).

Basic experiments
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 parameter 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.
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!
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

Demo applications - maintenance
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.
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.
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 reproducible

Demo applications – maintenance
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 monitor 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

Graph: Electron density vs. rf hours

- Wet clean
- One point – one wafer
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)

Demo applications – process electron collision rate vs. wafer [median]

- 5.3 15.3 25.3 4.4 14.4 24.4 4.5 14.5 24.5
- Date

- 30 50 70 90 110
- Collision rate [10^7 s^-1]

- 1 Metal 1 etch 2 Metal 2 etch 3 Metal 3 etch

Electron density vs. wafer [median]

- 0 10 20 30 40
- El. density [10^9 cm^-3]

- 5.3 15.3 25.3 4.4 14.4 24.4 4.5 14.5 24.5
- Date

- 1 Metal 1 etch 2 Metal 2 etch 3 Metal 3 etch

Demo applications – process electron collision rate vs. wafer [median]
Yield problem at DRAM product detected by electron density measurement in real time

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

Electron density vs. wafer

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Electron density vs. wafer

Electron density vs. wafer

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

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.

Mean value of electron density indicates chamber drift between wet cleans.

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

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

- 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

![Graph showing electron collision rate vs. wafer [rel. std. dev.]](image)
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
  - Automatical data handling
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 infrastructure:
  - 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!
Use of plasma parameters for data reduction at Advanced Process Control in high volume production

- Application of Advanced Process Control 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
Application of plasma parameters for Fault Detection and Classification

- Complex process parameters depend on tool and wafer impacts.
- 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 production:
  - 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.
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

![Graph showing electron collision rate vs. wafer for main etch and over etch]
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.