Monitoring of process stability and chamber matching by plasma parameter measurement using High speed- SEERS

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Outline

- High speed SEERS features
- Strategy of plasma parameter application within AEC/APC
- High speed SEERS application examples
  - Process stability
  - Chamber matching
  - FDC - Fault detection and classification
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High speed SEERS features
**Self Excited Electron Plasma Resonance Spectroscopy - How it does work**

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- RF up to 30\textsuperscript{th} harmonics
- Passiv, no impact on process
- Easy current sensor qualification

- SEERS model limits:
  - One RF frequency higher than ion plasma frequency (4 … 6 MHz)
  - Pressure max. 300mTorr

- Electron Collision Rate [s\textsuperscript{-1}]
  - Mean electron collisions with gas molecules
- Electron Density [cm\textsuperscript{-3}]
  - = Plasma Density

- Bulk Power [mW/cm\textsuperscript{2}]
  - Power dissipated by electrons in plasma

- DC Bias Voltage [V]
  - it’s well known
Dynamic effects in plasma: B-field rotation mode effect on process conditions - Results

Plasma parameter vs. Process time

Electron Density
Electron Collision Rate

B-field sine wave mode 0.5 Hz:

B-field square wave mode 0.25 Hz:
Dynamic effects in plasma: B-field rotation mode effect on process conditions - Discussion

- High speed SEERS modus: up to 15 measurements per second
- Electron collision rate and electron density show B-field mode (square or sinus) impact on process conditions.
  - Oscillation indicate electrically asymmetric chamber geometry
  - Electron density (plasma density) with sine wave B-field mode recipe indicates plasma instabilities
  - Phase shift between electron density (= plasma density) and electron collision rate (see B-field square wave mode 0,25Hz)
  - Hypothesis of phase shift root cause: Retardation between plasma excitation (electron density) and resulting gas composition
Dynamic effects in plasma: Plasma stabilisation at process start

- Process stability reached after about 20 s
- Plasma density oscillation caused by rotating B-field
Strategy of plasma parameter application within AEC/APC
The Plasma is your Tool

The chamber is the tool box only. The plasma in the chamber – that’s your Tool really.

- Some parameters can be measured, for example:
  - MFC gas flow, pressure …

- Other parameters cannot be measured, for example:
  - Gas adsorption and desorption at chamber wall = conditioning

- Processes on wafer surface are difficult to monitor.

Cathode, chamber kit, RF Power installation

Plasma

Wafer

E-chuck
Plasma parameters = key indicators of process conditions

How electron collision rate $v_e$ and electron density $n_e$ indicate process conditions in plasma (simplified equations):

$$v_e = \frac{e^2}{\varepsilon_0^2} \frac{n_e^2}{B^2} \left( \frac{p_{gas}}{k_B T_{gas}} \right) \left( \frac{p_1}{p} v_e \sigma_1 (v_e^{-1}) + ... \right)$$

$$n_e \sim B_0^2 U_{peak} f(p_{Gas})$$

- Plasma parameters summarise process impacts, which are:
  - known and measured easily
  - known and difficult to measure
  - unknown and cannot be measured at all

- Plasma parameters = key indicators of process conditions
Plasma parameter application as a process health indicator in AEC/APC

- Detection of statistical significant process drift:
  - Caused by measurable effects with very high sensitivity
  - Caused by indirectly measurable effects
  - Caused by recipe parameters, chamber, wafer

- Data compression:
  - By the measured parameter, „by Physics“ itself

Plasma parameters are real time process health indicators.

Plasma parameters give you direct information about the plasma - your Tool.
High speed SEERS applications within AEC/APC

Process stability
Chamber matching
FDC
Process stability & chamber matching of an etch process

Electron collision rate vs. Date [mean]

Mainframe 1
4 chambers

Mainframe 2
4 chambers

Mainframe 3
4 chambers

Electron density vs. Date [mean]
Process stability and chamber matching of mainframe 2

- Superimposition of long term drift and short term process condition drift in plasma
- Wet clean impact on process conditions is clearly seen by both parameters
Process stability and chamber matching of mainframe 2, chamber B and C

- Electron collision rate and electron density indicate different effects on process conditions (see page 11)

Electron collision rate vs. Date [mean]
- Date: 20.08.02, 09.09.02, 29.09.02, 19.10.02, 08.11.02, 28.11.02, 18.12.02
- Electron collision rate [s⁻¹]

Electron density vs. Date [mean]
- Date: 20.08.02, 09.09.02, 29.09.02, 19.10.02, 08.11.02, 28.11.02, 18.12.02
- Electron density [cm⁻³]
Wet clean monitoring with plasma parameters of an etch chamber

Wet clean abnormal

- Electron collision rate shows normal and abnormal wet clean clearly
FDC: E-chuck fault detection in an etch chamber

- Electron collision rate and electron density show e-chuck faults clearly.

Plasma parameter vs. date [rel. std.dev.]

- Plasma unstable after wet clean
- Plasma stable after ESC exchange

Electron collision rate and electron density show e-chuck faults clearly.
FDL: Detection of unstable plasma and arcing in an etch chamber with rotating B-field

Detection of unstable plasma and arcing by electron density (= plasma density) measurement
FDC: Conditioning monitoring and leak detection of CVD process

Electron collision rate vs. Date [mean]

Leak detected

Electron density vs. Date [mean]

Abnormal first wafer effect after dry clean

Tool down
Conditioning monitoring – First wafer effect after dry clean of CVD process

is normal  ↔  First wafer effect  →  is abnormal

First wafer effect after dry clean is normal

First wafer effect after dry clean is abnormal

Stability and FDC
FDC: First wafer effect and leak detection - discussion

- **Conditioning:**
  - Dry clean every 5th wafer ➔ Impact on chamber wall surface
  - Chamber re-conditioning takes about 20 .. 25s on following product wafer
  - Conditioning effects are not detected by tool parameters
  - ➔ Electron collision rate = „Conditioning indicator“

- **Leak detection:**
  - Leak was detected by increase of chamber pressure and electron collision rate
  - But electron collision rate rise was about ten times higher than pressure increase!
  - ➔ Electron collision rate detects very small leaks, which cannot be found using tool parameters, e.g. pressure
Chamber matching: CVD chamber redesign effect on process stability

- Same recipe after chamber redesign ➔
- Electron collision rate less noisy, but significant drift (gas composition)
- Increase of electron density indicates increased plasma density (effective power input)
Summary

- Plasma parameters, like electron collision rate and electron density, characterise process conditions in plasma directly.
- High speed SEERS enables real time plasma parameter measurement with fast response time ➔ Short dynamic processes in plasma can be monitored.
- Applications of High speed SEERS were demonstrated with etch and CVD processes:
  - Process stability monitoring
  - Chamber matching
  - FDC
- Plasma parameters can be used as real time process health indicators.