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Long-term Stability and FDC of Plasma Parameters for Trench Si Etching Using Lam TCP 9400 PTX

Teina Pardue
Teina.Pardue@fairchildsemi.com
Fairchild Semiconductor
3333 West 9000 South
West Jordan
Utah 84088-8853
USA

Michael Klick
Michael.Klick@asinst.com
ASI Advanced Semiconductor Instruments
Rudower Chausse 30
D12489 Berlin
Germany

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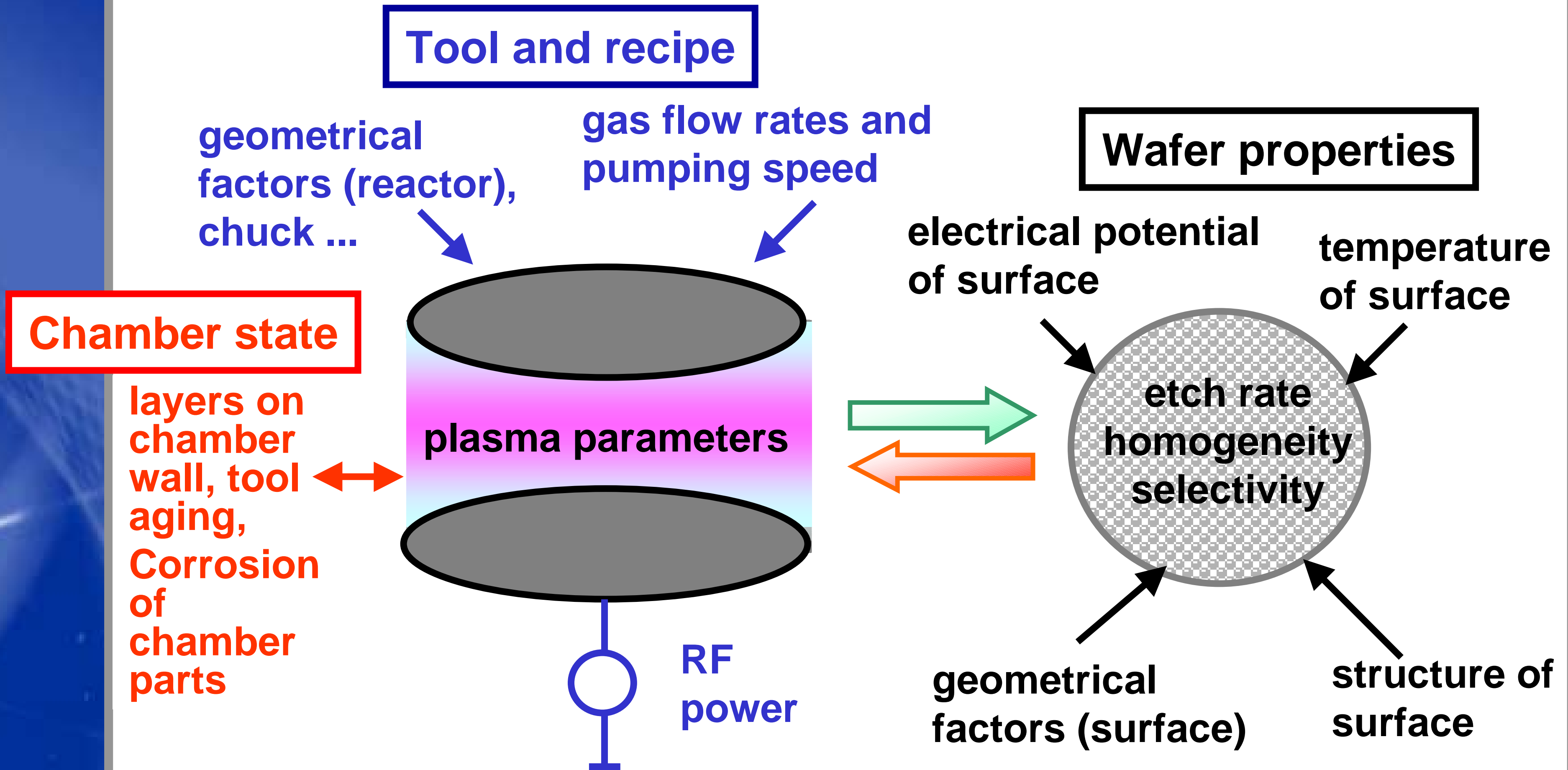
Motivation

There are no simple answers



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Outline

- Monitoring of plasma parameters
- Long term study for Si trench etch process
- Finger print at Lam TCP 9400 PTX
- Fault detection
- Conclusions

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Monitoring of plasma parameter

Plasma parameters, technology, and process results

Monitoring of plasma parameter

Assumptions and output of SEERS/Hercules

- Assumptions of SEERS theory:
  - Ionization and changing of electron temperature in sheath region is neglected because of low pressure < 100 Pa
  - Electron plasma frequency > RF frequency > ion plasma frequency
  - Plasma sheath assumed as one dimensional
- Hercules is based on SEERS and determines
  - Electron density, reciprocally averaged
  - Electron collision rate
  - Power (total) dissipated in plasma body (by electrons)

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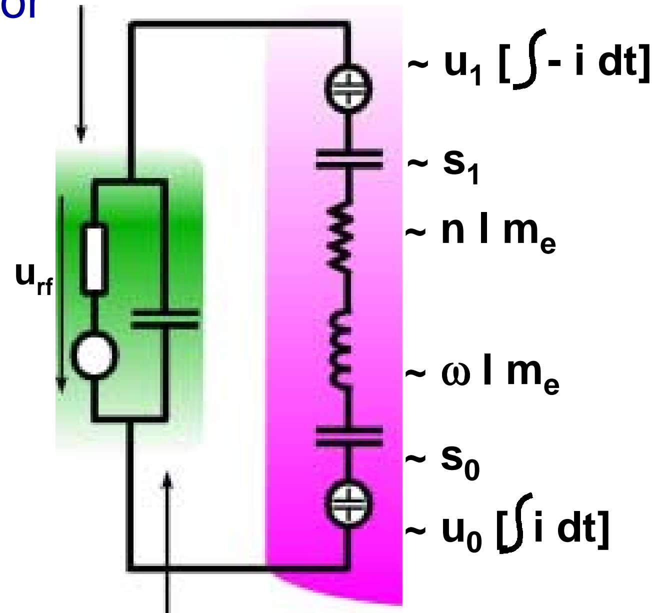
Monitoring of plasma parameter

SEERS Equivalent circuit of the RF discharge

matchbox and
generator



$\sim u_1 \, [\int - i \, dt]$ nonlinearity sheath plasma-wall

$\sim s_1$ linear „part“ of wall sheath

$\sim n \, l \, m_e$ ohmic part of plasma bulk (ohmic and stochastic heating)

$\sim \omega \, l \, m_e$ inertia (imaginary) part thereof

$\sim s_0$ linear „part“ of rf sheath

$\sim u_0 \, [\int i \, dt]$ nonlinearity sheath rf electrode

feed-through and
stray capacitance

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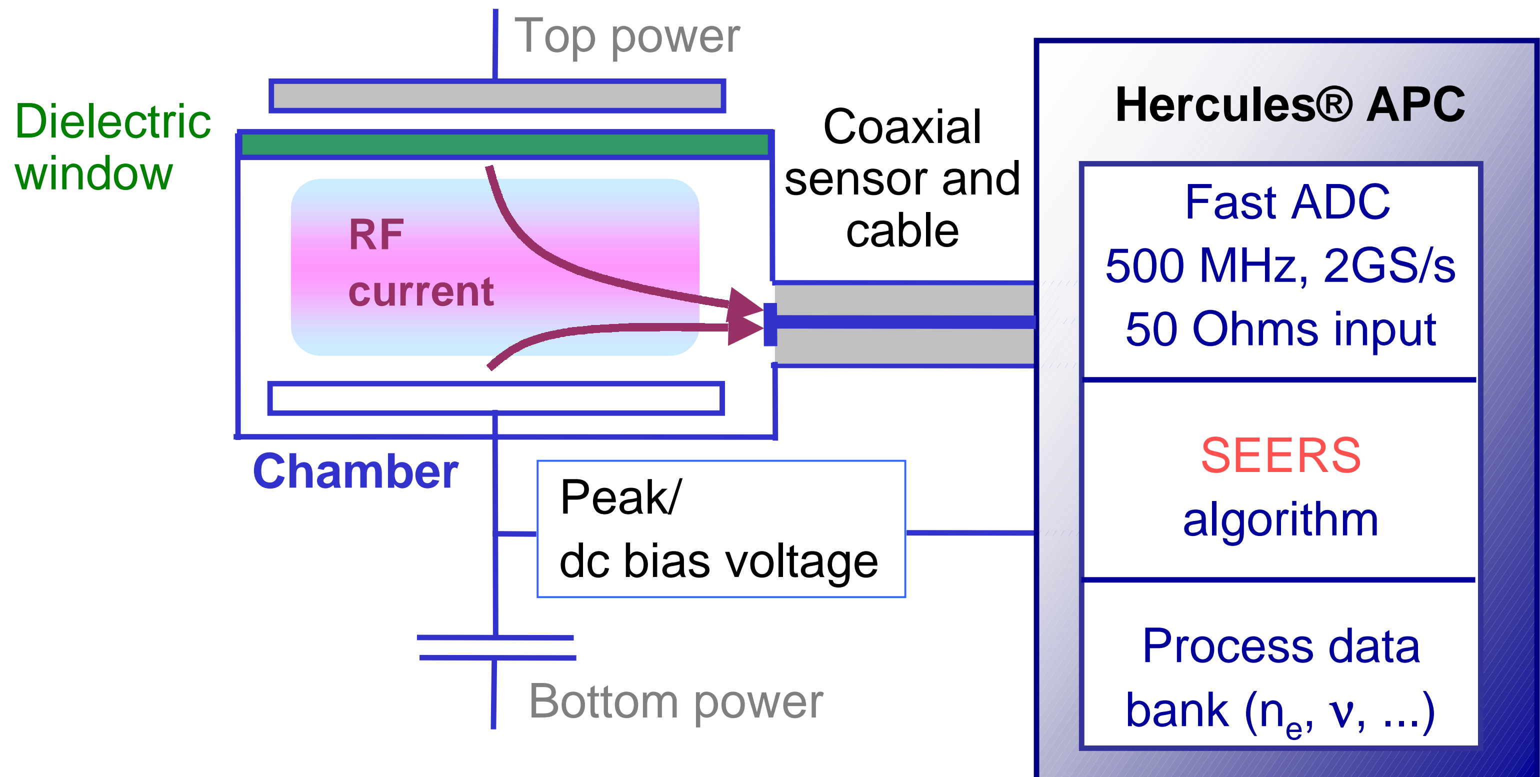
Monitoring of plasma parameter

The principle of SEERS

Nonlinearity between voltage and displacement current.
Sensor measures fraction of displacement current.



RF current ➔ SEERS model ➔ plasma parameter in real time

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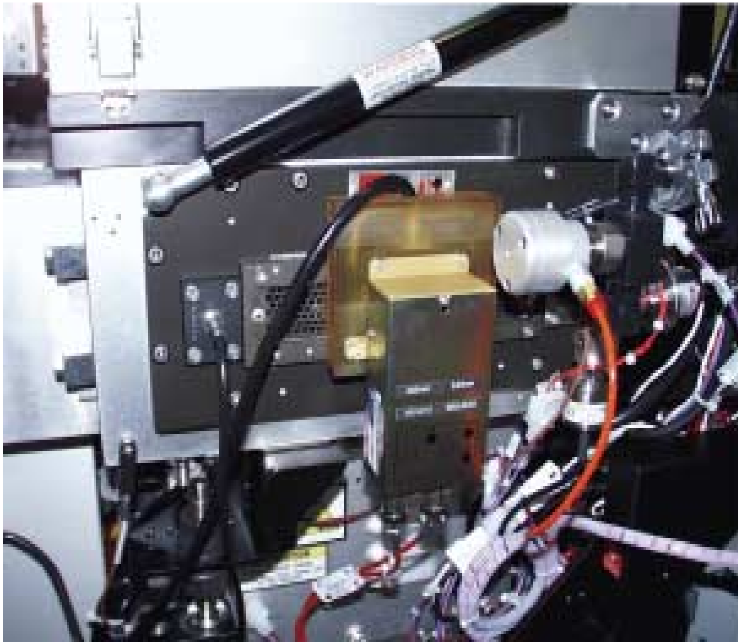
Monitoring of plasma parameter

Sensor for TCP 9400 PTX



Sensor Signal weak because of Liner

New Platen improves Signal to Noise Ratio

Source: Dr. Volker Tegeder, Infineon Technologies SC300, AEC/APC-Symposium XIII 6.-11.10.2001, Banff, Can.

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Monitoring of plasma parameter

Characteristic parameter: Effective collision rate of electrons

- **Electron collision rate ν_{eff}**
- depends on power and pressure (recipe)
- depends on gas mixture (recipe)
- impact of electrons on chemistry
- feedback from chemistry via cross sections and
- relative concentration of species

stochastic heating (sheath)

gas pressure

collision cross-section

$$\nu_{eff} \approx \frac{1.6}{l}\sqrt{\frac{U_{bias}}{2\pi m_e}} + \frac{p}{kT_n}\sum_i \frac{p_i}{p}\sigma\left(\frac{1}{v_e}\right)v_e$$

He Cl₂ polymer particle

gas temperature

relative concentration

low	medium	large

ν_{eff}: number of collisions of one electron with neutrals per second

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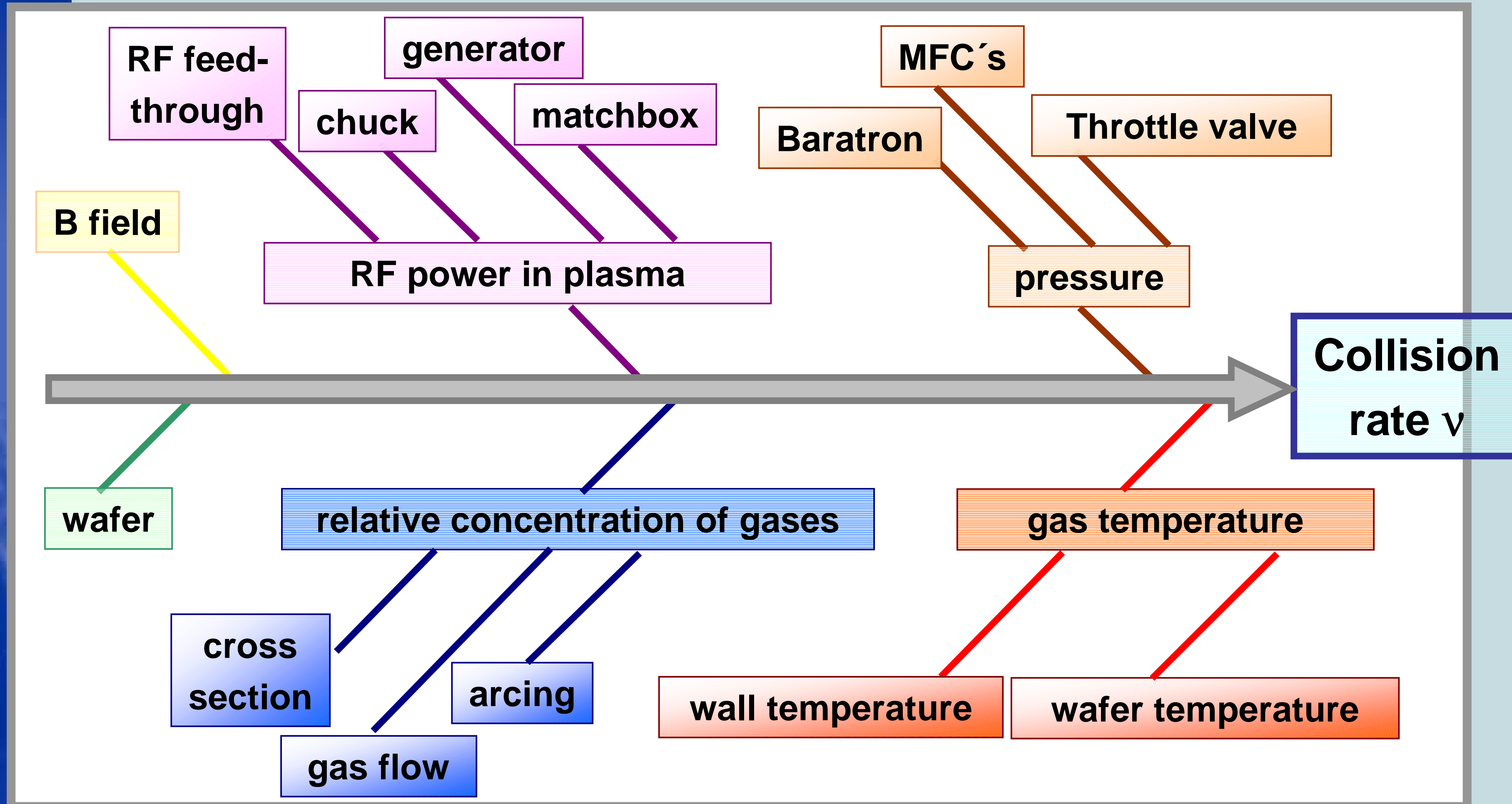
Monitoring of plasma parameter

Electron collision rate - a universal control parameter



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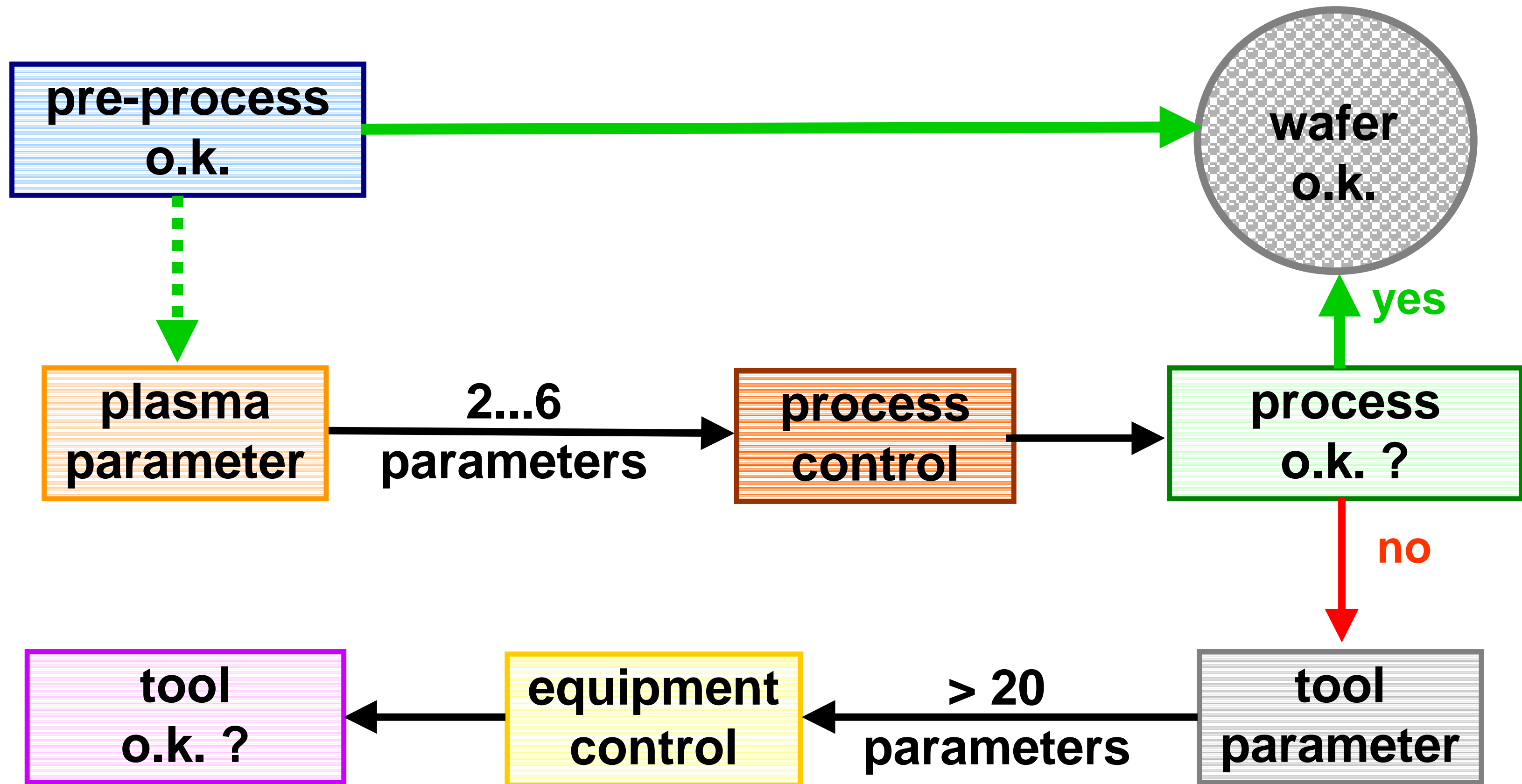
Monitoring of plasma and tool parameters

Process control by plasma parameters



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Si Trench process

Setup

- Tool: Lam TCP 9400 PTX
- Process: Si trench based on HBr and Cl chemistry
- Multi-step recipe including break-through and main etch
- Main focus in this study:
  - Main etch stability
  - Efficiency of Wafer-less Auto Clean (WAC), SF_6/O_2
  - Check of Preventive Maintenance (PM) by plasma parameter (electron collision rate)
  - Tool Fault Detection and Classification (FDC)

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Si Trench process

Main issues

- Long term stability is influenced by:
  - Wafer-less Auto Clean (WAC) after every production wafer
  - Product mix (minor issue)
  - Scheduling of Preventive Maintenance (PM)
- Fault detection and classification
  - Aging and corrosion of chamber parts
- Target: Control and optimization of WAC and PM
- **Main benefits:**
  - **Increased up-time and availability for production**
  - **Cost reduction of PM's**
  - **Reduction of cost of ownership (CoO)**

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Wafer-wise long term trend

Main etch mean of electron collision rate

Wafer
Electron collision rate →
Wafer →
Test / conditioning wafer

Long term trend for one product group (> 6000 wafers)

2. Fault level

1. Normal level

3. Normal level again after additional PM

Benefit: Easy and fast production control.

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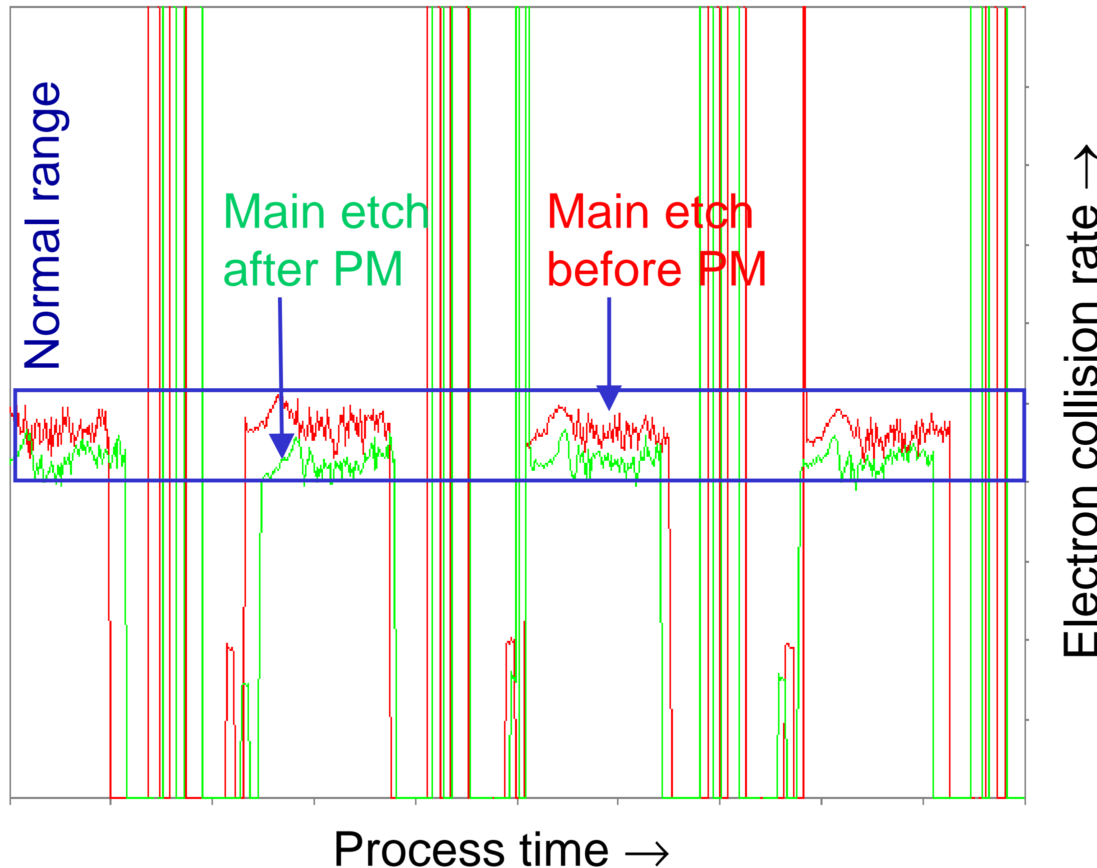
Fingerprint before and after PM

Efficiency of wafer-less auto clean controlled by electron collision rate



- The level of the electron collision rate before and after PM (wet clean) shows a variation of about 5%.
- This indicates the high efficiency of the WAC, applied after every wafer during normal operation.
- **Low effort for wet clean and reconditioning due to WAC controlled by electron collision rate.**

Benefit: Reduced maintenance effort.

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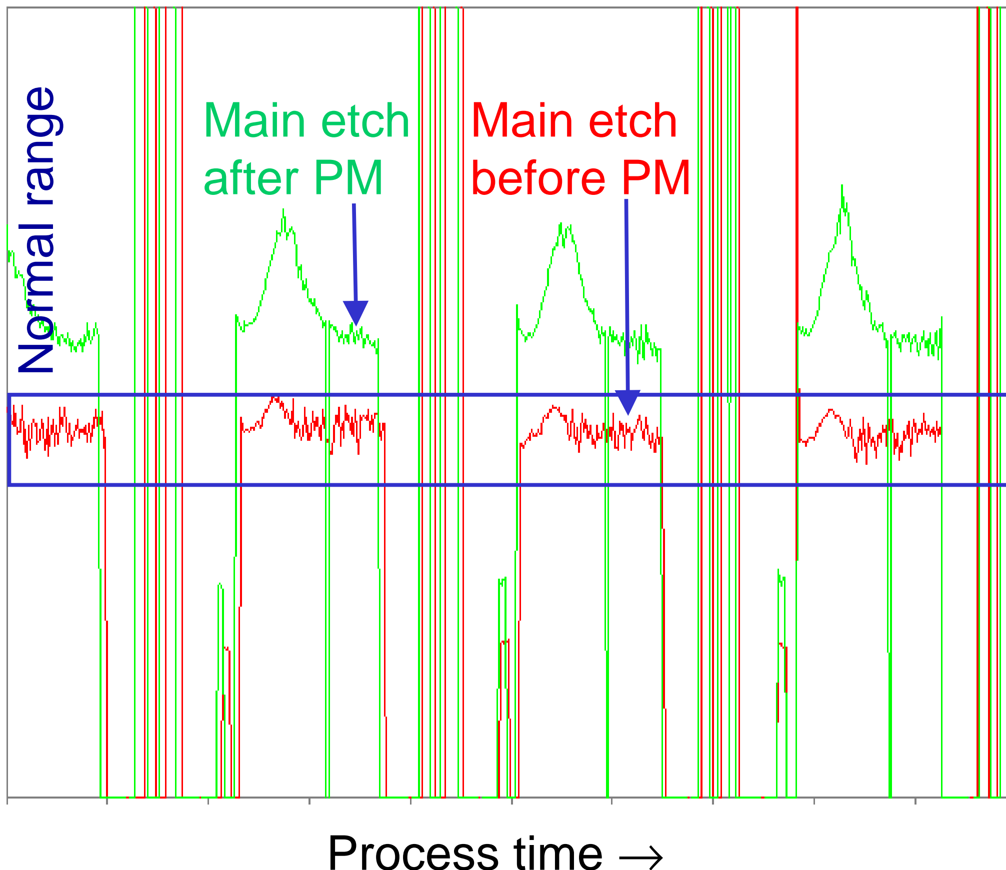
Fingerprint before and after PM

Chamber fault detection detected by electron collision rate



- The variation is out of the range and increased by approximately 20%.
- The collision rate shows an increase, instead of the normal decrease, before and after PM (wet clean).
- This indicated an equipment fault.
- Corroded gas ring was identified as root cause after extra next PM.
- Due to the early detection only slight impact to product.

Benefit: Fast and easy chamber check after PM.

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Conclusions

- The main etch is stable and shows no drift between the PM‘s, in particular due to the WAC.
- Thus the difference of the chamber rate state before and after PM given by the electron collision rate is small and was verified by test wafer and product data.
- The electron collision rate shows a high sensibility to tool faults as corroded chamber parts.
- Plasma parameters are useful and sensible control parameters, their sensibility is, at least for the process under consideration, much higher that the product parameters.

References

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Related publications

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Related publications

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- www.asinst.com

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  by Optical Emission Spectroscopy and
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- Application of plasma parameter measurement by SEERS on oxide etch process development for new DRAM shrink generations
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