CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

01.03.2002
Page 1

Tool- and process comparison of 200mm- and 300mm- Si plasma etch processes by Optical Emission Spectroscopy and Self Excited Electron Plasma Resonance Spectroscopy

Siegfried Bernhard siegfried.bernhard@infineon.com
Dr. Andreas Steinbach andreas.steinbach@infineon.com

Center for Development and Innovation
Infineon Technologies Dresden www.infineon.com

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Acknowledgement

- The authors would like to thank
  - Frank Schäftlein, Uwe Leucke
    Applied Materials
  - Dr. Michael Klick and Lutz Eichhorn,
    Advanced Semiconductor Instruments
  - Uwe Rudolf, Uwe Köckritz, Marcus Schardin
    Infineon Technologies Dresden
  - The whole APC Team of Infineon Technologies Dresden

- The results presented in this paper were supported partially:
  - by the EFRE fund of the European Community
  - and by funding of the State Saxony
    of the Federal Republic of Germany, project SENSOR.
- The authors are responsible for the content of the paper.

Outline

- Motivation
- Measurement techniques
  - Self Excited Electron Plasma Resonance Spectroscopy
  - Multichannel Optical Emission Spectroscopy
- Maintenance - Verification of tool problems
  - Temperature drift and RF power variation
  - Chamber matching
- Process transfer and process stability
- Production - Productivity improvement
  - Dummy clean
  - Conditioning
- Summary

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Motivation

- Si etch is one of the most sophisticated plasma etch processes at in DRAM technology
  - è reliable measurement methods for process control are needed
- The step from 200mm to 300mm wafers is a big challenge
  - For hardware reliability
  - And process transfer
  - Effective methods for easy process control and tool failure detection are needed to achieve a fast production ramp up
- Productivity improvement is an important task of daily business, independent of wafer size.

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

CDI

Measurement techniques

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Measurement techniques

- We combined two different in- situ plasma measurement techniques
- Self Excited Electron Resonance Spectroscopy (SEERS)
  - Electron collision rate
  - Electron density
  - Bulk power = power dissipated by inelastic collisions between electrons and gas molecules
- Multichannel Optical Emission Spectroscopy (OES)
  - 1024 channel full spectrum analysis
  - Spectrum analysis by Principal Component Analysis (PCA)

Infineon technologies

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Plasma Monitoring System Hercules using Self Excited Electron Resonance Spectroscopy (SEERS)

CDI

RF current
RF voltage

↓

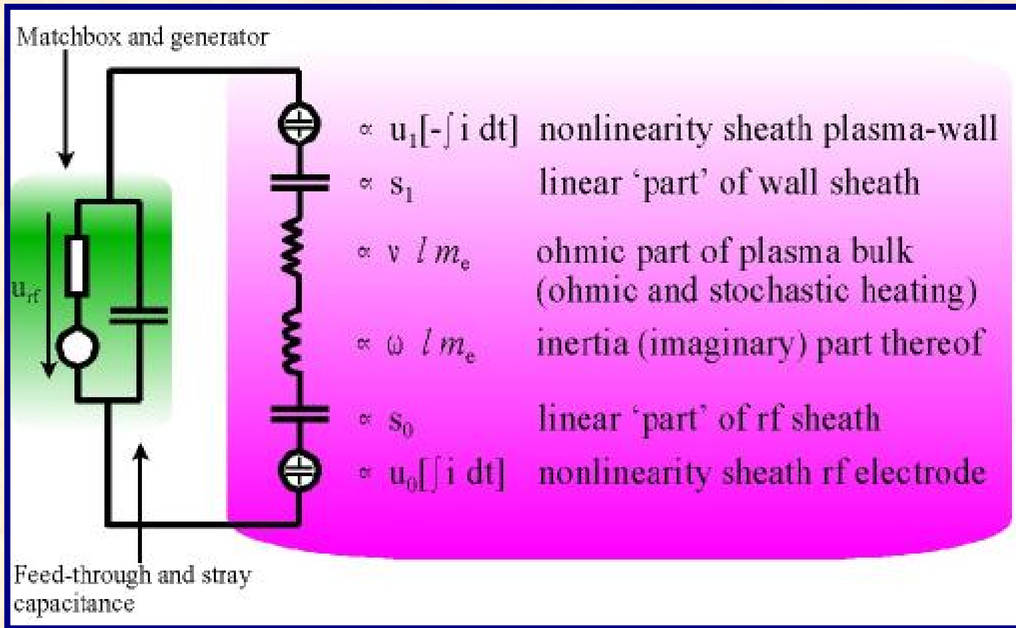
FFT

↓

Model SEERS

↓

Electron collision rate
Electron density
Bulk power
DC bias voltage



- Self Excited Electron Plasma Resonance Spectroscopy
  - Passive electrical method
  - Integral physical parameters

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

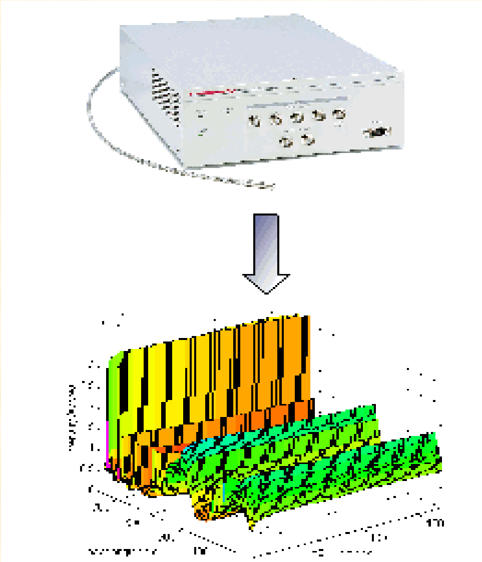
Spectrometer Hamamatsu MPM using Multichannel Optical Emission Spectroscopy (OES)

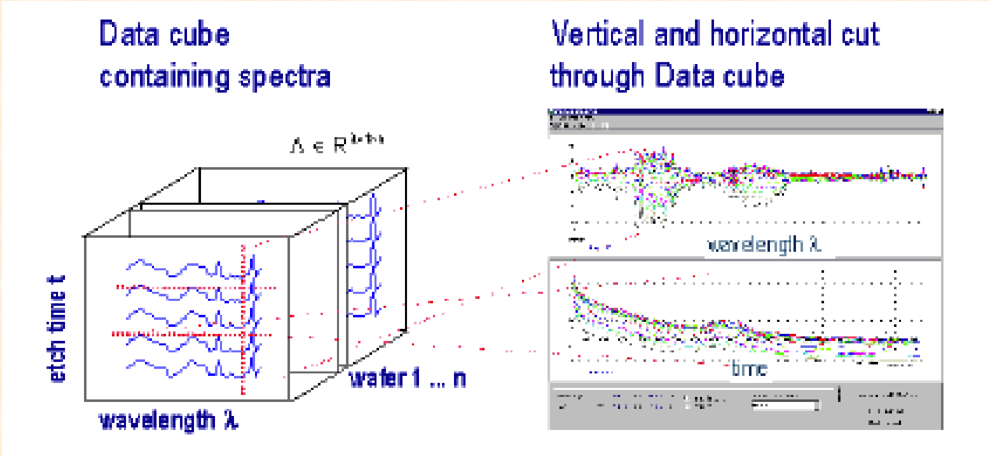
CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR





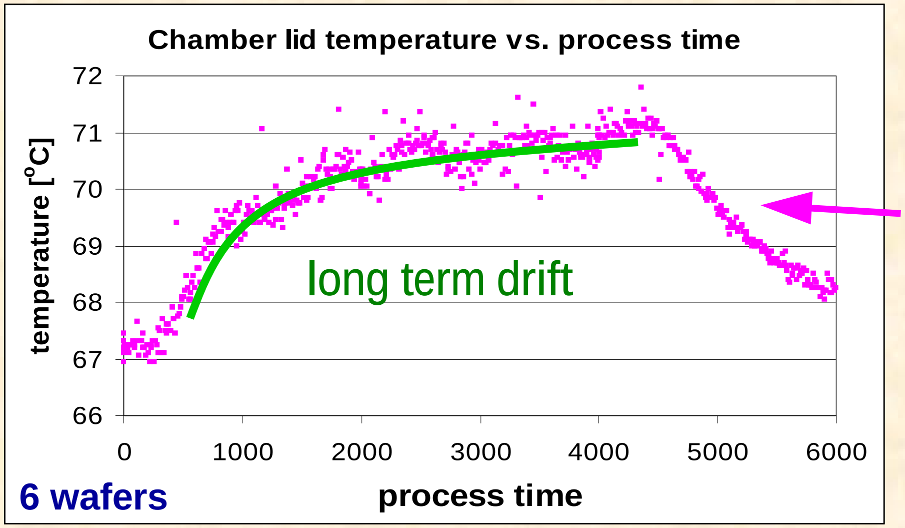
- Multichannel optical emission spectrometer
  - Wavelengths 200nm -950nm
  - 1024 channel CCD array

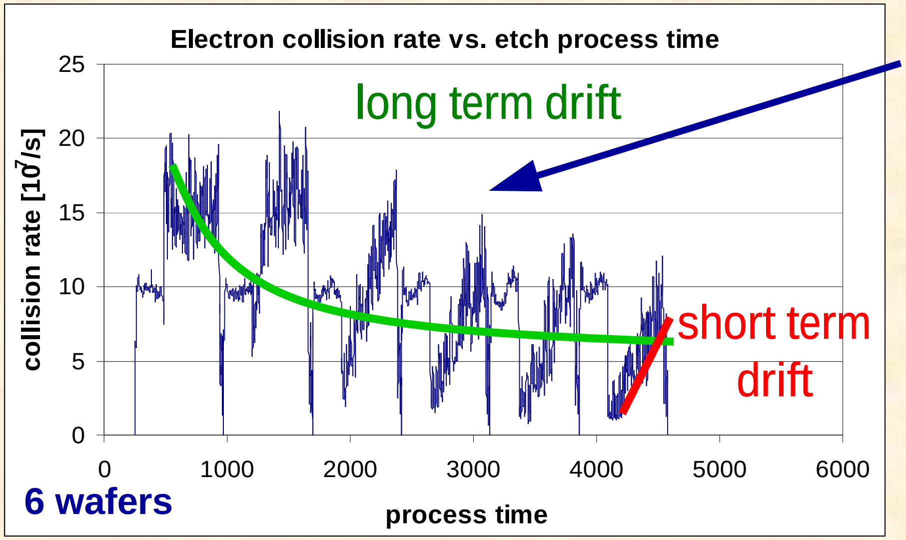
Maintenance –
Verification of tool problems

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Temperature stability check by measurement of chamber lid temperature and electron collision rate

CDI





- Check of temperature stability at a Si etch chamber
- Lid temperature measurement outside
  - Indicates long term drift over 6 wafers
  - Reacts slowly
- Electron collision rate shows two different drifts
  - Long term drift, decreasing over 6 wafers
  - And short term drift, increasing during high power step

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

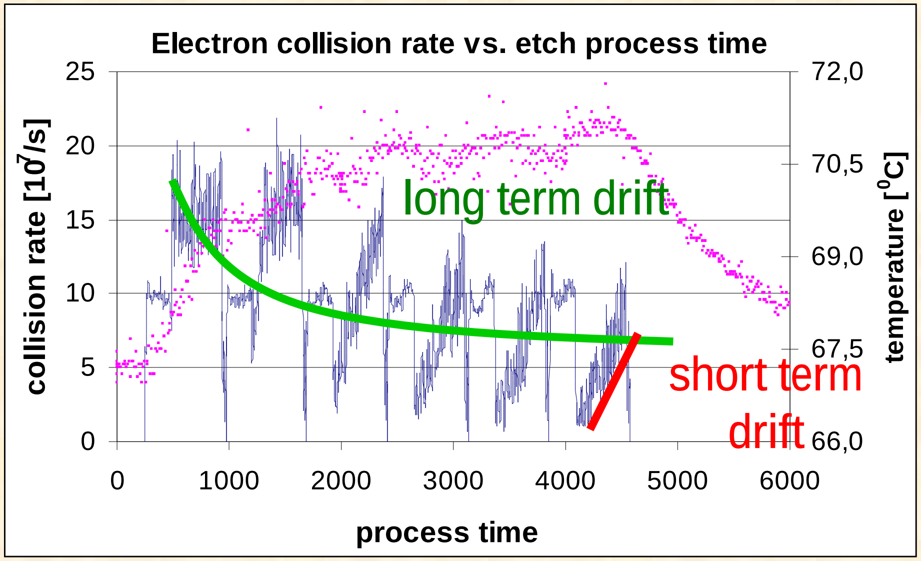
Explanation of electron collision rate measurement at (in) chamber temperature drift experiment

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR



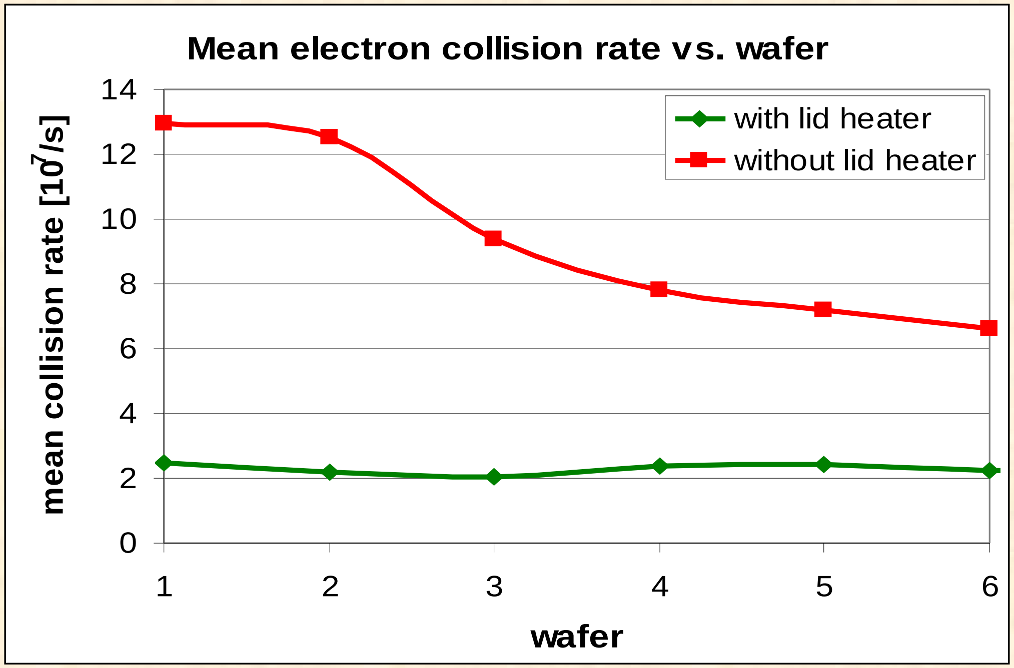
- Electron collision rate is a complex process parameter:
  - Temperature of chamber parts ➔ gas temperature
  - Chemical reactions ➔ gas composition
  - RF power input ➔ electron temperature

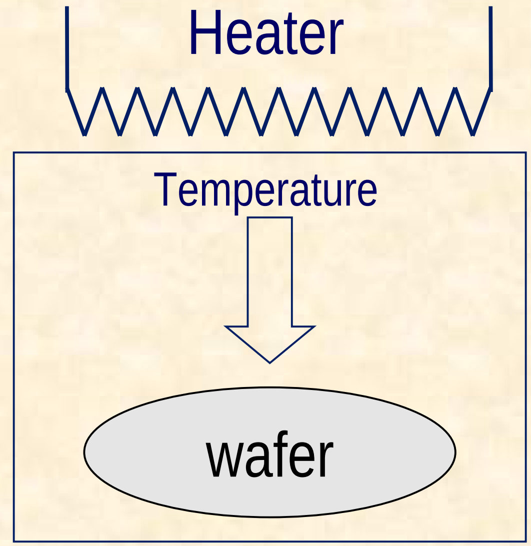
$$n = n_{Stoch} + \sqrt{\frac{8\,k_B T_e}{p\ m_e}} \cdot \frac{P_g}{k_B T_N} \cdot \sum_k \frac{p_k}{P_g} s_k$$

- ➔ Electron collision rate integrates many influences on process stability = data compression „by physics“
- That´s why it detects all these effects

Improvement of chamber temperature stability by improved chamber lid heating

CDI





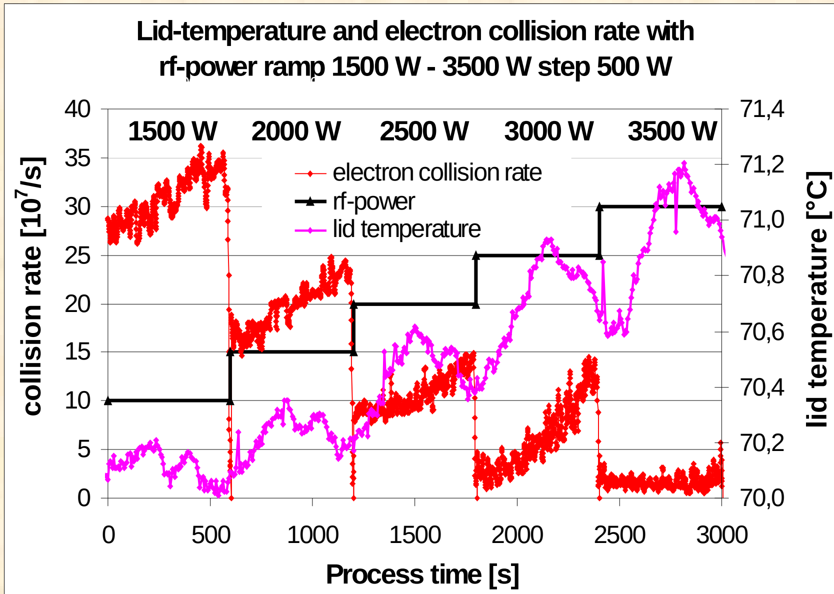
- Comparison of chamber without and with improved chamber lid heater
  - Without improved lid heater: electron collision rate decreases → insufficient temperature stability, temperature increases
  - With improved lid heater: electron collision rate is stable
- Benefit: Efficiency of new chamber lid heater was verified in real time

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

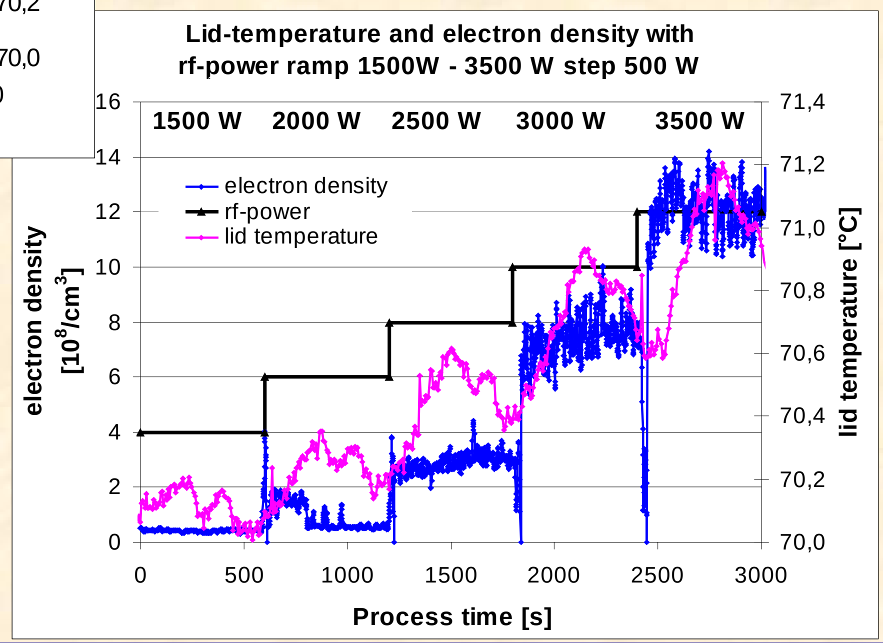
Project SENSOR

Verification of temperature drift caused by RF power variation



q RF power é è Drift of electron collision rate indicates:

- ø è Chamber lid temperature é
- ø è Chamber kit and wafer surface temperature é



q RF power é è Increase of electron density

q Temperature drift of chamber lid, chamber kit and wafer surface have no significant impact on electron density

Infineon technologies

CDI

Siegfried Bernhard
Andreas Steinbach

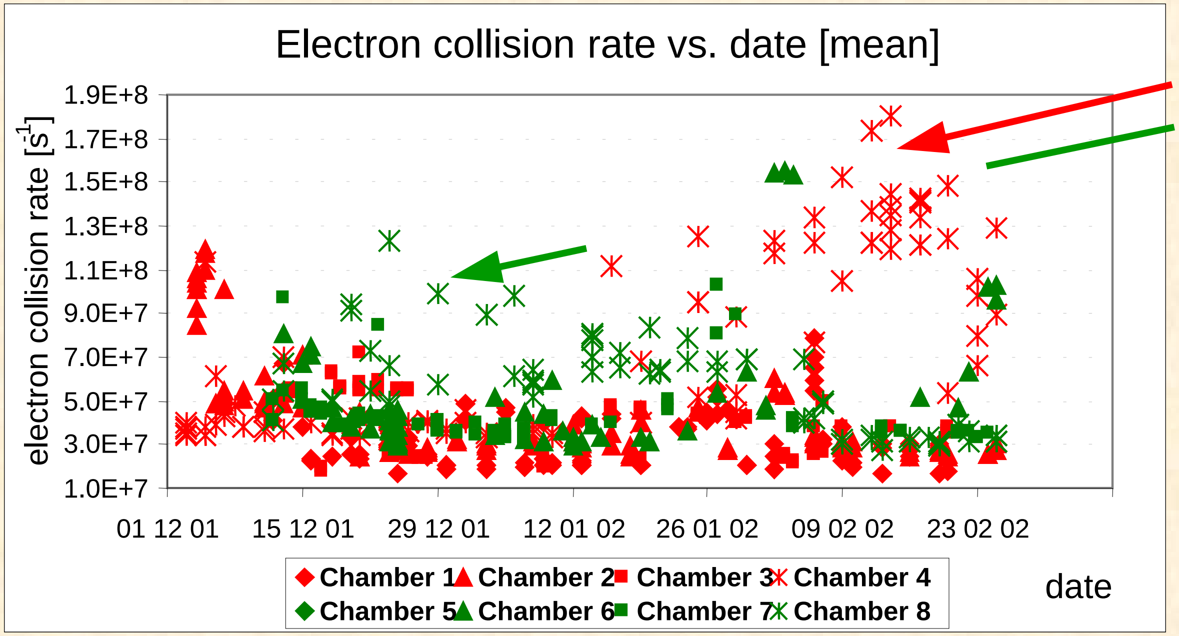
Center for Development and Innovation

Infineon Technologies Dresden

APC

Project SENSOR

Chamber matching of 300mm Si etch chambers by plasma parameter measurement during tool test



Drift of chambers 4 and 8 (mainly due to maintenance measures) was only detected by plasma parameter measurements

- Plasma parameter measurement during regular tool check on blank test wafers. Electron collision rate is much more sensitive than etch rate or uniformity measurement
- Benefit: Success of maintenance measures, their real impact on process conditions can be checked in real time

Siegfried Bernhard
Andreas Steinbach

Center for Development and Innovation

Infineon Technologies Dresden

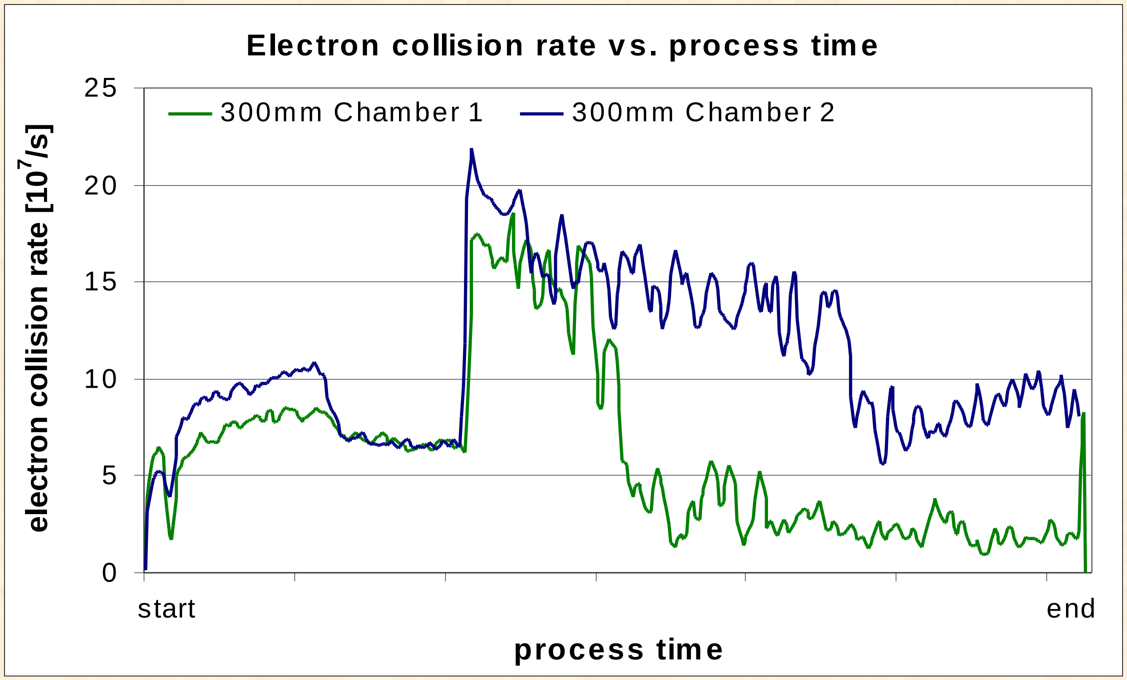
CDI

APC

Project SENSOR

Chamber matching of Si etch chambers by plasma parameter measurement on product wafers

CDI



Nominal identical hardware and process in both chambers
è
but different etch results

- Electron collision rate indicates significant difference of process conditions in chamber 1 and chamber 2
- Benefit: Real time chamber matching of process conditions on product wafers

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

CDI

Process transfer and process stability

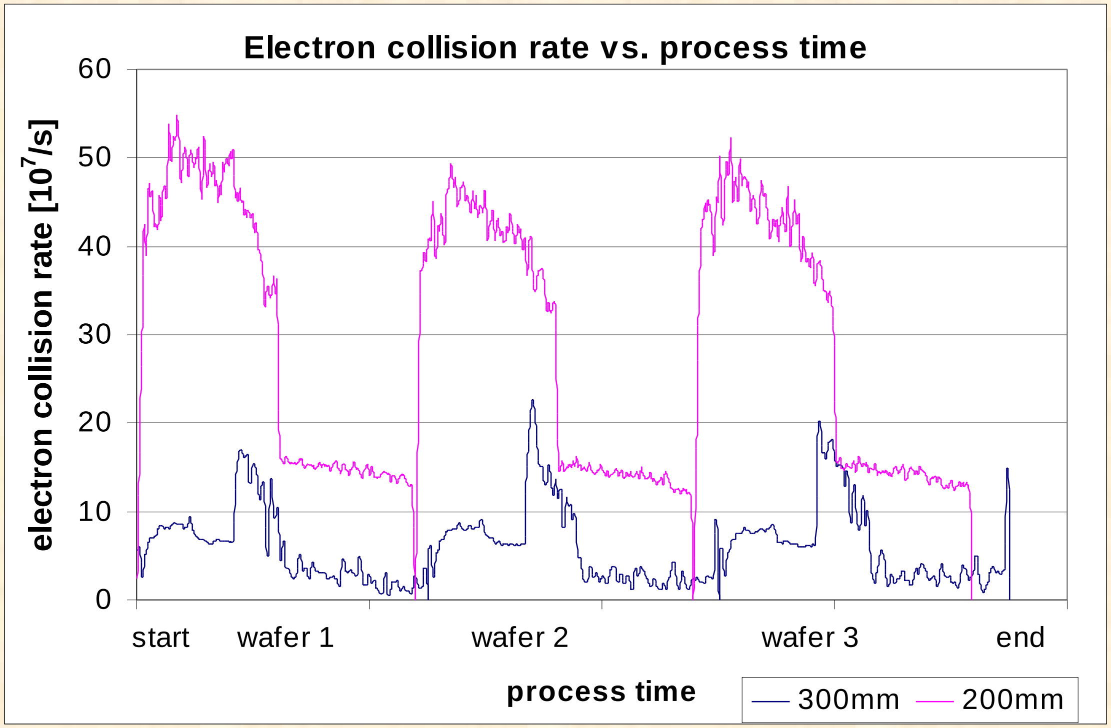
Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Comparison of process conditions in 200mm and 300mm Si etch chambers

CDI



Very similar chamber types are used for 200mm and 300mm wafers to achieve identical process conditions

Siegfried Bernhard
Andreas Steinbach

Center for Development and Innovation

Infineon Technologies Dresden

- Identical process results demand identical process conditions.
- Process conditions in 200mm and 300mm chambers can be compared on product wafers by plasma parameter measurement directly.
- Benefit: Effective monitoring of process transfer on product wafers

Project SENSOR

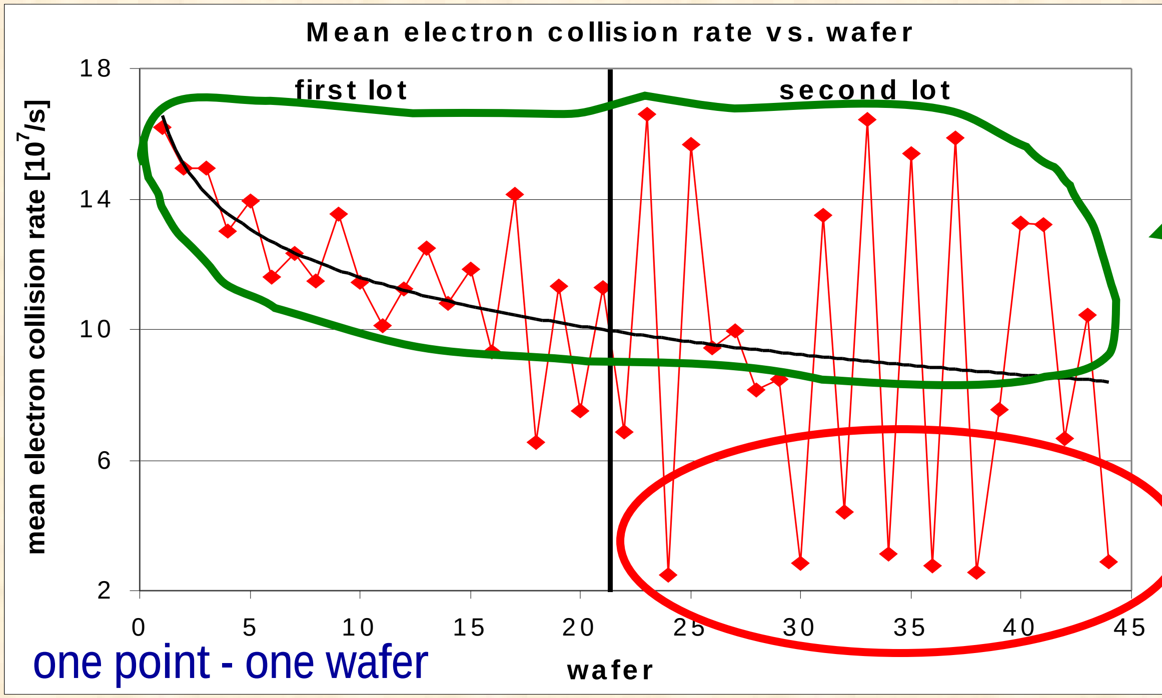
Real time monitoring of pre- process quality by electron collision rate

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

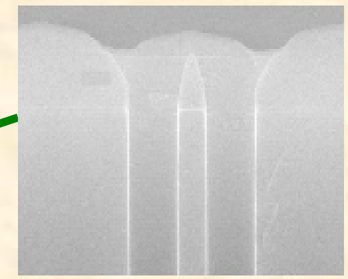
CDI

APC

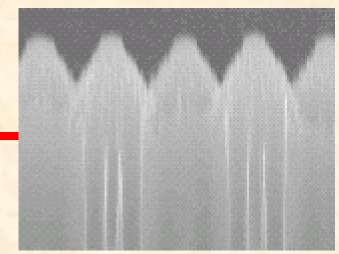
Project SENSOR



Good etch result



Bad etch result



- Wafer to wafer signature at second lot caused by alternating mask quality, due to pre– processes (Litho, CVD, ...)
- Drift during processing of both lots is caused by tool impacts
- Benefit: Real time monitoring of wafer quality depending on pre-process

Monitoring of product mix impact on process stability

- Product mix impact of two different Si etch processes on process stability was monitored by
  - Plasma parameter measurement using Self Excited Electron Resonance Spectroscopy (SEERS)
  - Multichannel Optical Emission Spectroscopy (MPCA) at wavelengths from 200nm to 480nm during main etch step
- Analysis of measurements
  - Plasma parameters are calculated by plasma monitoring system Hercules internally in real time, no further calculation necessary
  - Analysis of optical emission spectra offline by Multiway Principal Component Analysis

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

CDI

APC

Project SENSOR

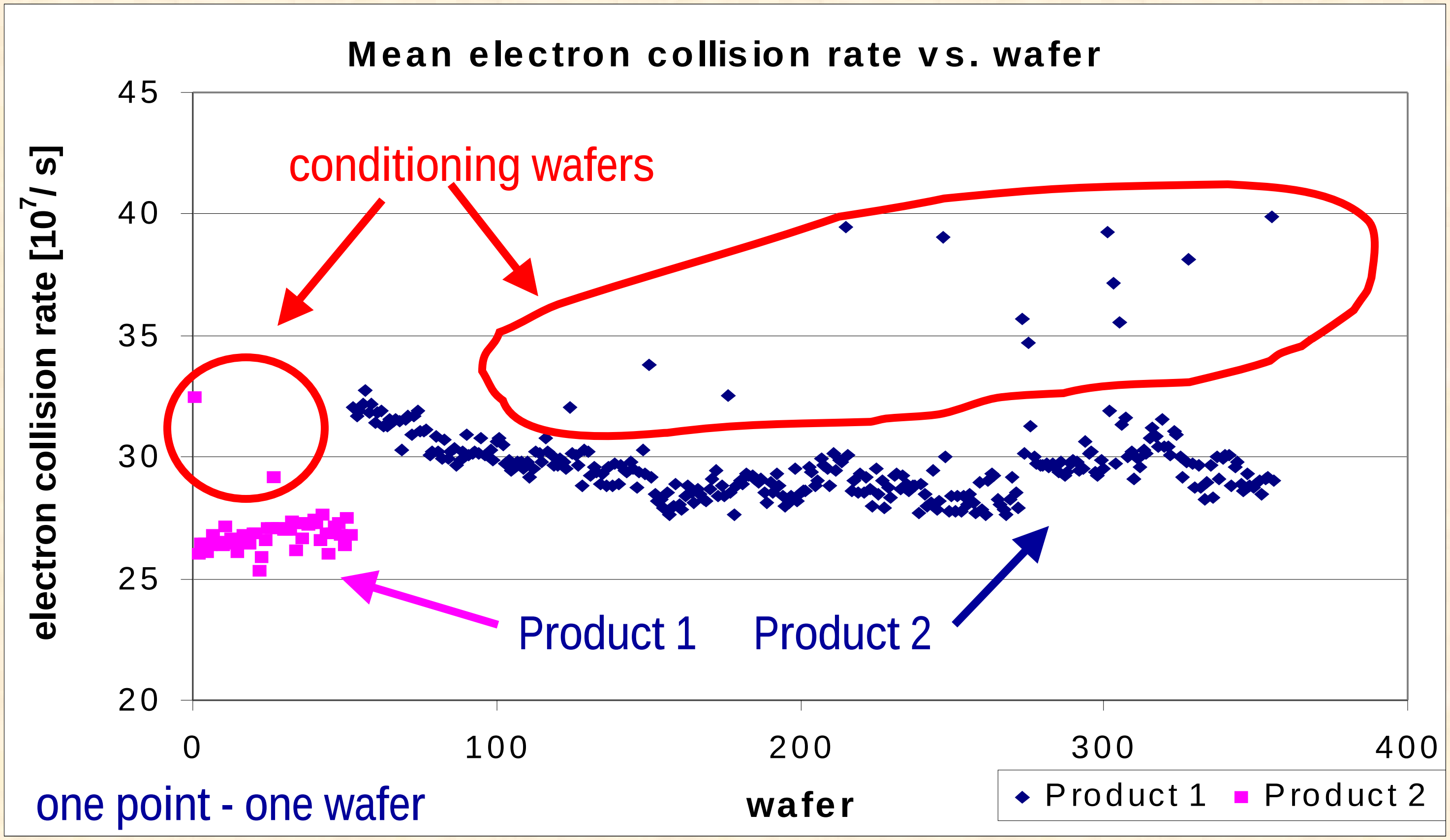
Real time monitoring of product mix impact on process stability by electron collision rate

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR



- Compare with results on next page
- For discussion see next page

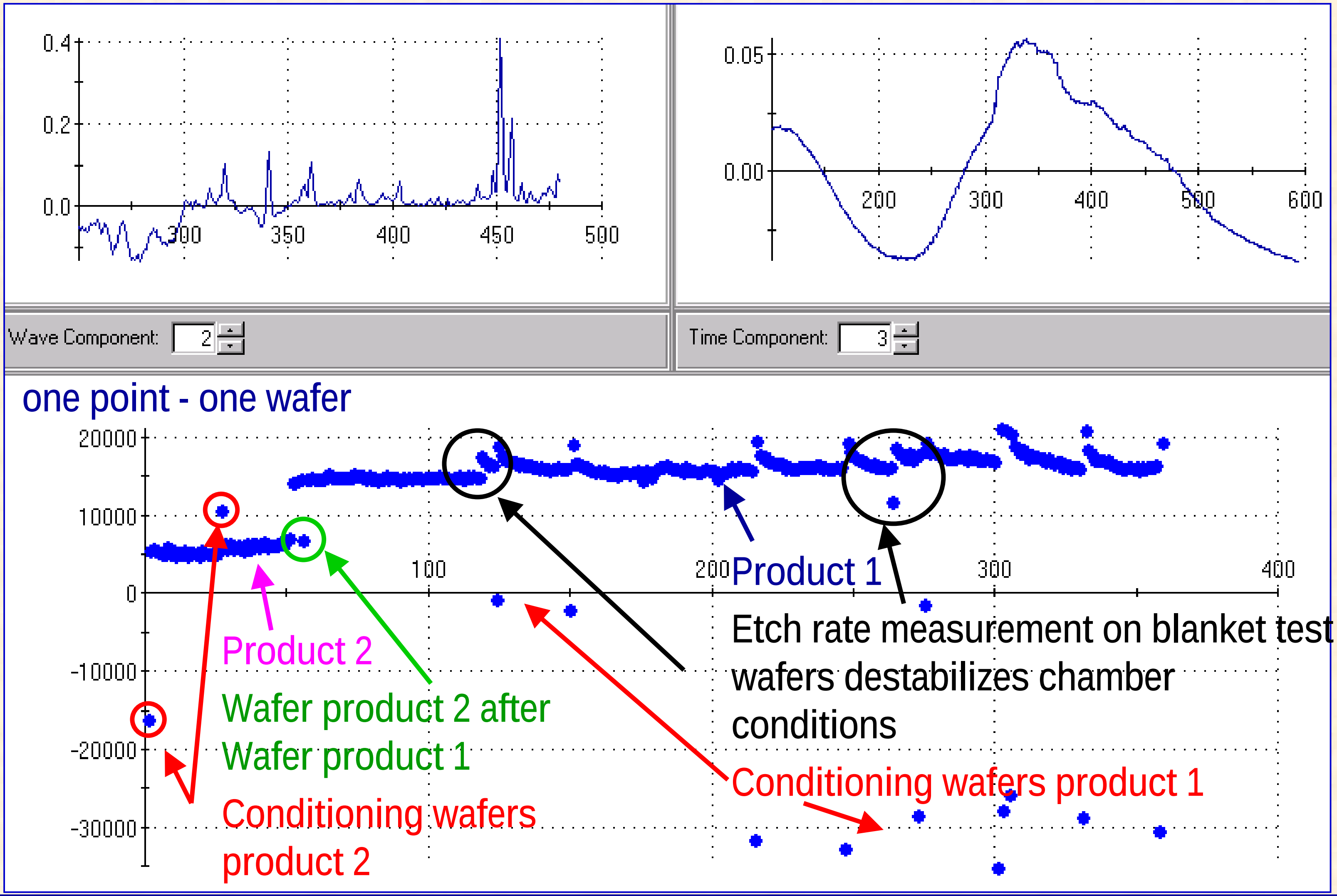
Real time measurement and off- line analysis of product mix impact on process stability by MPCA

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR



Real time monitoring of product mix impact on process stability - Discussion

- Discussion of measurement results
  - No interaction between product 1 and product 2, both products run very stable
  - Product 1 shows strong first wafer and conditioning effects
  - Etch rate measurement on blank test wafers destabilizes process conditions significantly
- Comparison of both measurement methods:
  - Plasma parameter measured in real time
  - Integrate many impacts on process conditions
- OES with MPCA
  - Offer more details, but offline calculation necessary
- Benefit of both methods
  - Process and product stability of product mix can monitored by both methods

CDI

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

CDI

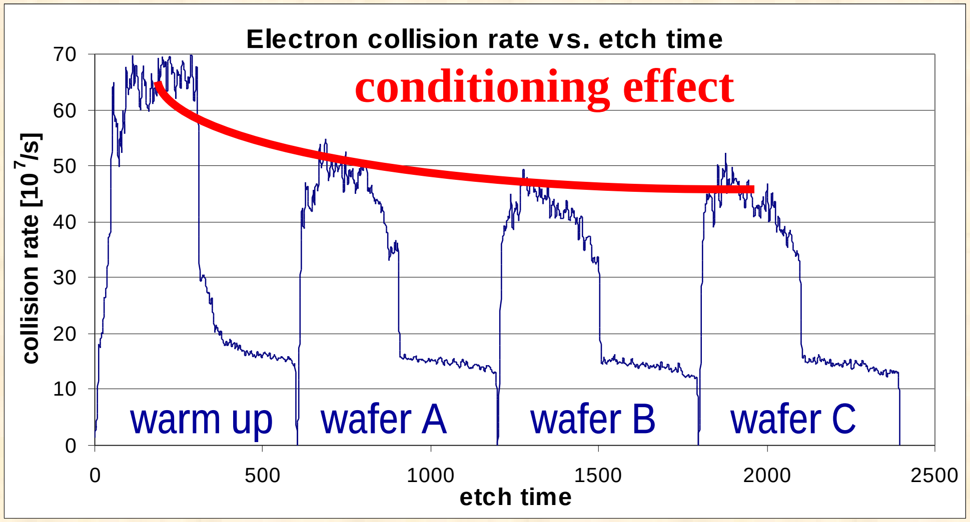
APC

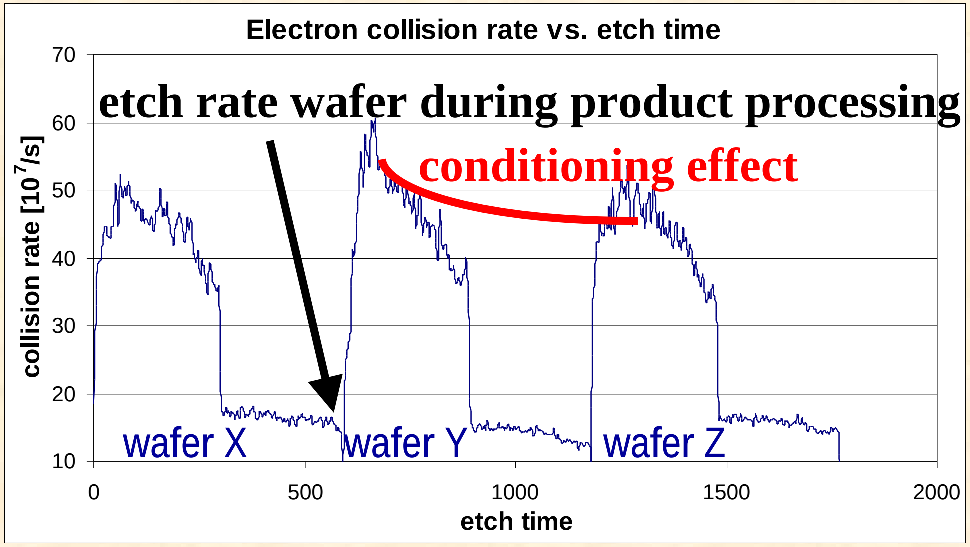
Project SENSOR

Productivity improvement

Optimization of conditioning and first wafer effects using measurement of plasma parameters

CDI





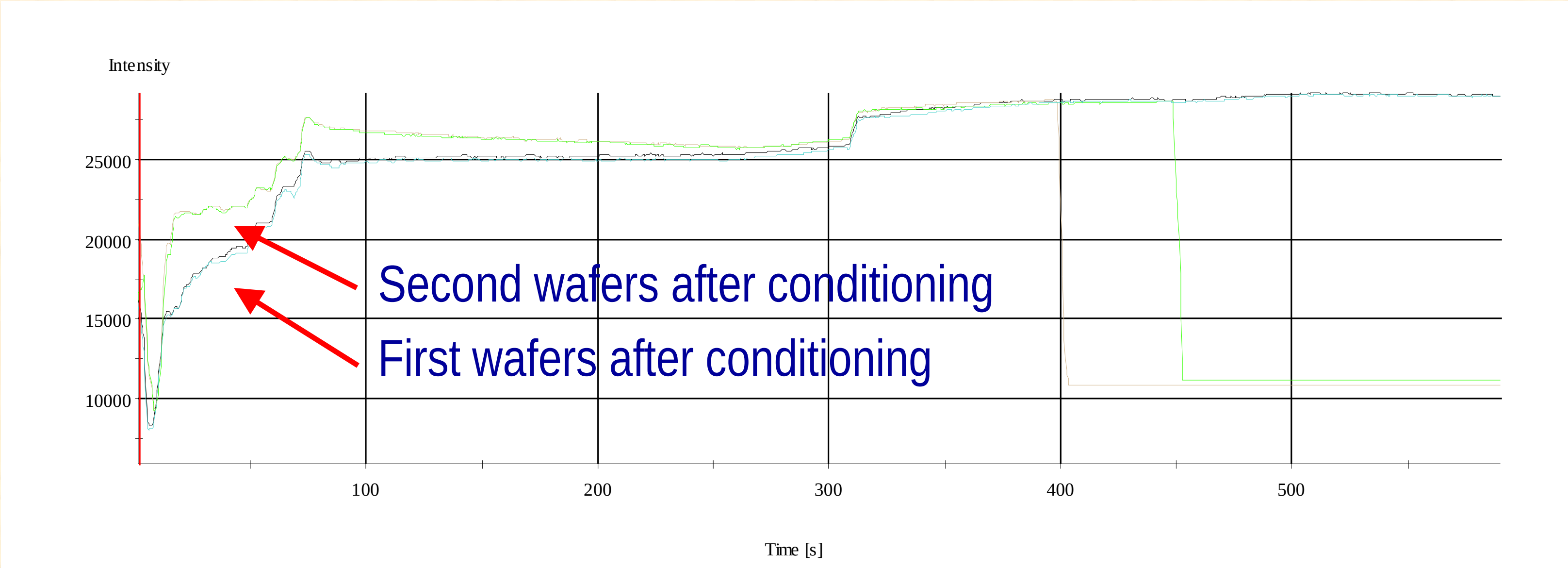
- Electron collision rate shows conditioning impact and first wafer effect in real time
- Etch rate measurement on blanket test wafer destabilizes chamber conditions between wafer X and wafer Y
- First wafer effect from wafer Y to wafer Z

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

APC

Project SENSOR

Optimization of conditioning and first wafer effects using OES



- Two different conditioning recipes were tested
- The time resolved signal of Fluorine verifies the first wafer effect
- Optimized conditioning recipe: Reduced conditioning time and the same acceptable first wafer effect
- Benefit : Monitoring of conditioning efficiency è productivity improvement

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

CDI

APC

Project SENSOR

Optimization of plasma dummy clean by OES - Measurements

Comparison of different plasma cleans, Discussion on next page

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

CDI

Project SENSOR

Optimization of plasma dummy clean by OES - Discussion

- Current plasma dummy clean procedure
  - Clean after each wafer
  - Independent from wafer type
  - Clean without endpoint, by time
- Significant endpoint signal at wavelength 850nm
  - Endpoint time ca. 60-70 sec.
- No clean activity during clean after conditioning wafer
  - Plasma clean after conditioning is not necessary
- No differences between plasma clean with low pressure step and clean with long high pressure step only (blue line)
- Benefit : Plasma dummy clean improved, **clean time reduced**

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

Siegfried Bernhard
Andreas Steinbach
Center for Development and Innovation
Infineon Technologies Dresden

CDI

APC

Project SENSOR

Summary

- In situ measurement methods like OES and SEERS are suitable for advanced process control in high performance semiconductor industries
- The measurement techniques are very sensitive to hardware and process problems and indicate these very early
- We are able to use both measurement techniques for
  - Verification of different tool problems
  - Process transfer
  - Productivity improvement
- There is a big benefit, but not always given in Euro or Dollar because non scrapped wafers and shorter process development are difficult to quantify!
- The process engineers will have to learn to use the power of advanced process control daily