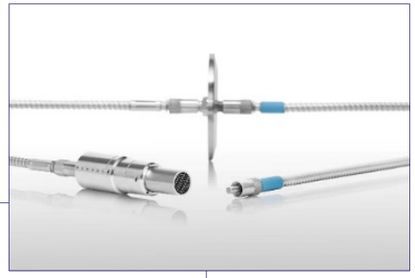
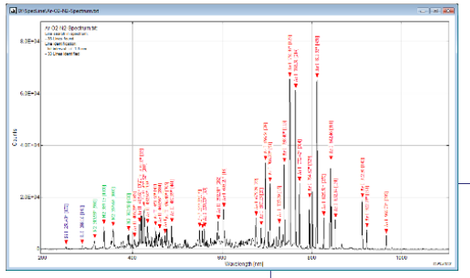
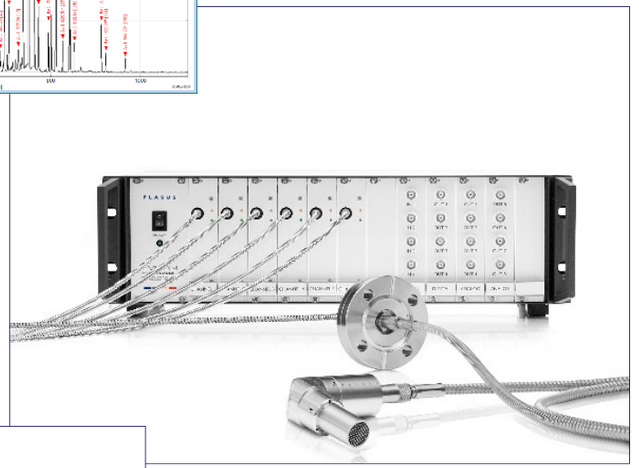
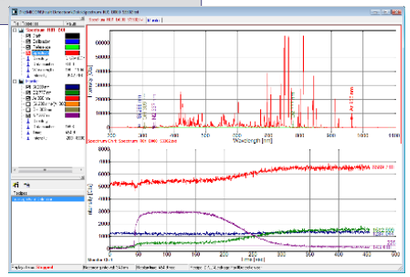
PLASUS Products
for
Spectroscopic Plasma Monitoring and Process Control





Turn-key solutions
for
production lines and R&D





Plasma Processes in Thin Film Production

Understanding the main tool in a variety of production steps

Analysis of plasma parameters	Better understanding of plasma process	New technologies
Optimizing plasma process	Improving production process	Improved products
Monitoring of process properties	Process fault detection	Quality control
Control of production process	Improved process stability	Higher production efficiency

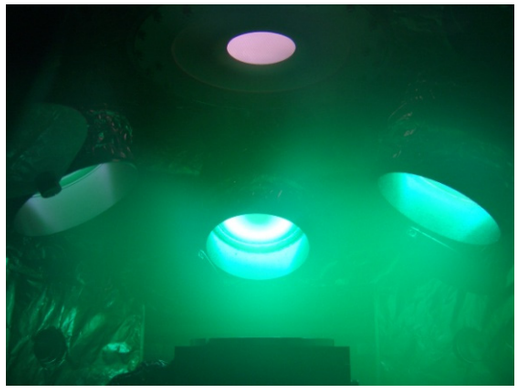
▶ **Analysis and control process plasma require flexible diagnostic method**

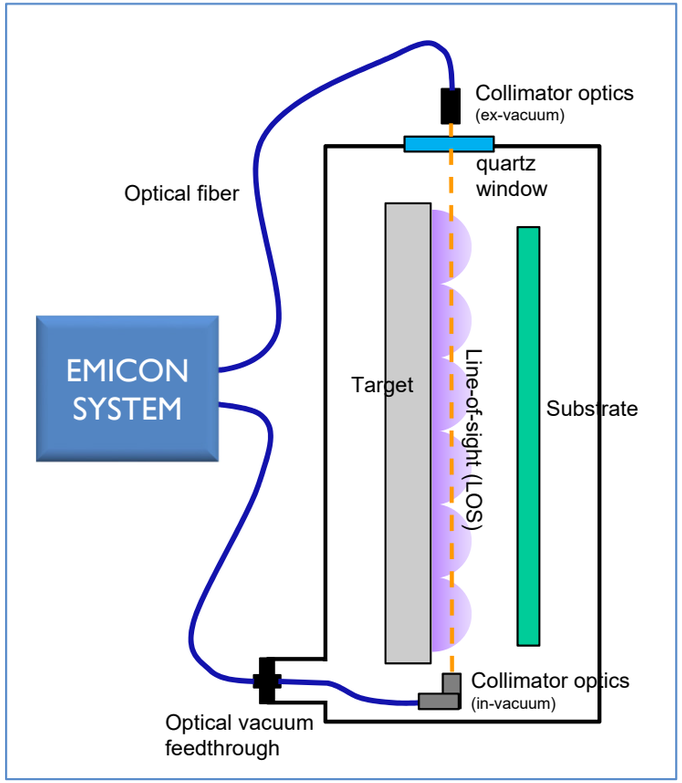
Spectroscopic Plasma Monitoring

based on
Optical Emission Spectroscopy (OES)

Method for establishing process control:

Measurement of plasma radiation in spectral range 200 – 1100 nm
- ↳ Analysis of plasma radiation provides densities of plasma species
  - ↳ Real-time monitoring of plasma densities reveals process conditions
    - ↳ Feedback to machine and control of plasma process



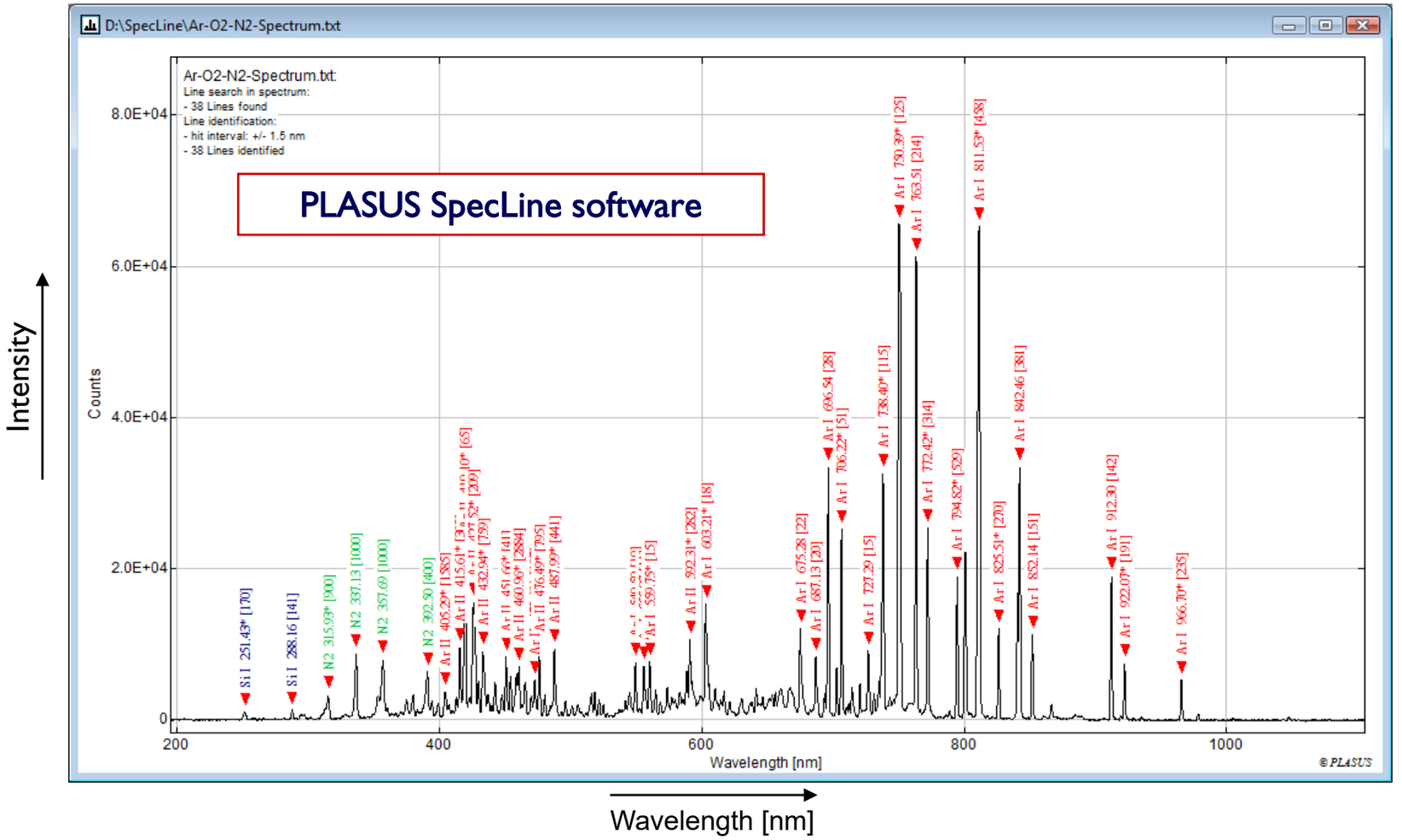


Advantages:

Easy set-up and mounting
Observation through chamber window or in-vacuum optics
No disturbance of process

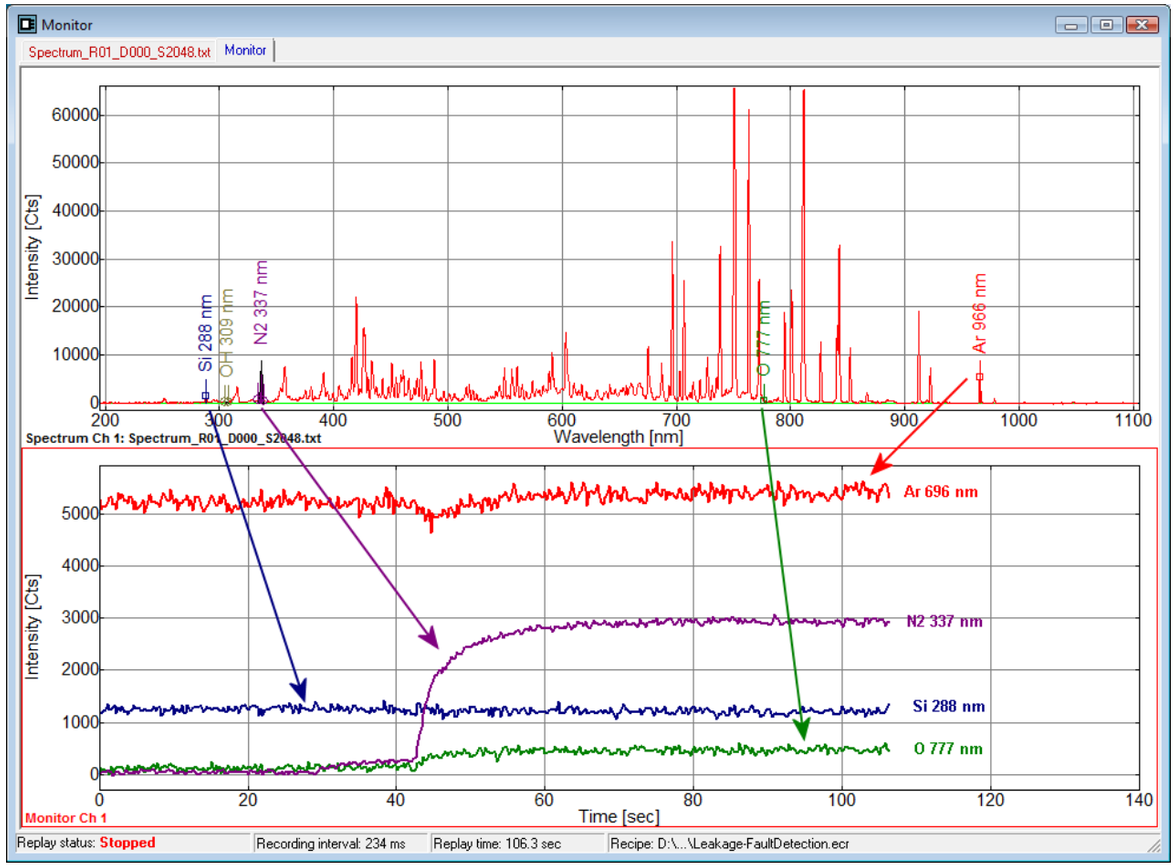
Process Setup

Identification of process relevant plasma species



Spectroscopic Plasma Monitoring

Real-time observation of line intensities



$$I(t) \sim n_e X(T_e)\ n(t)$$

Features:

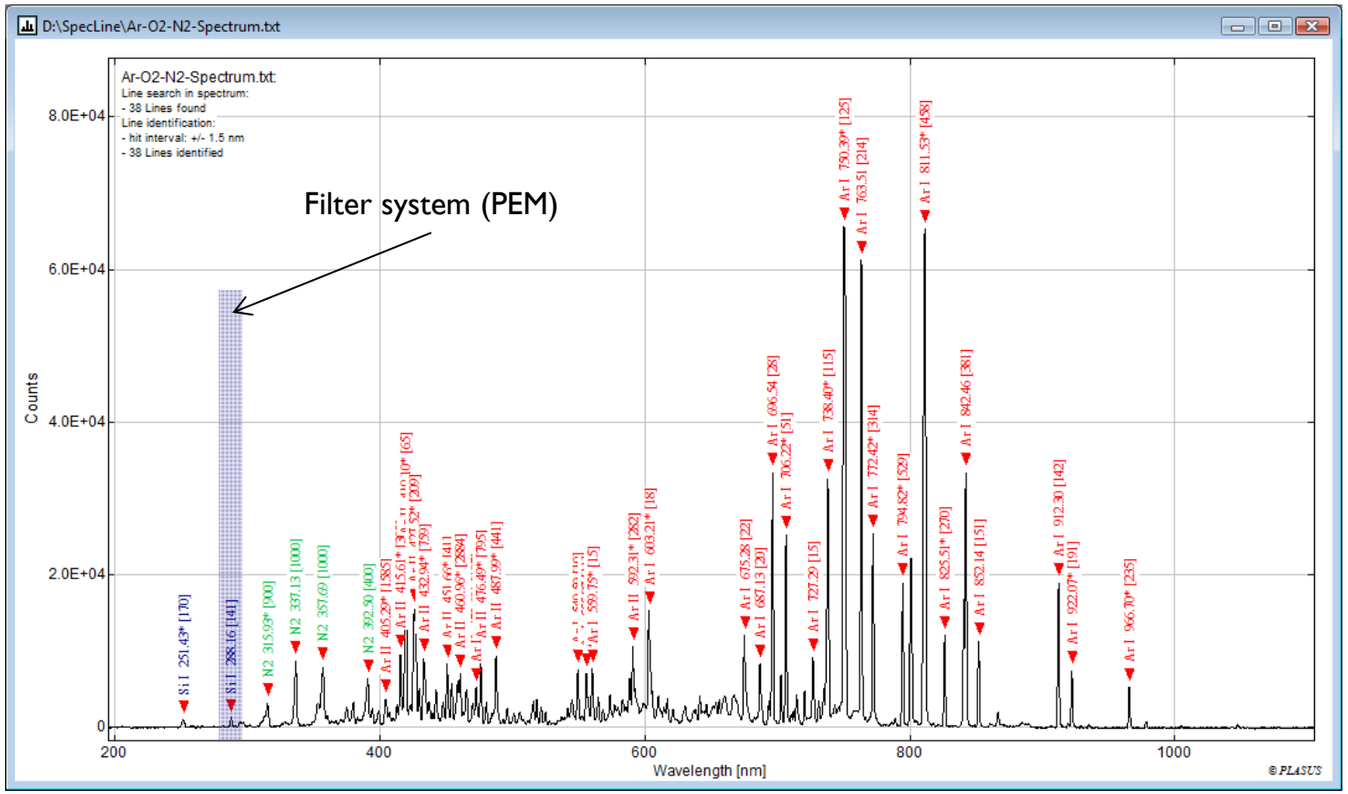
Simultaneous acquisition of all wavelengths
Real-time observation of plasma densities
Instant notice of change in plasma conditions
Real-time evaluation and analysis of process condition

Benefit:

Monitoring of process conditions
Optimizing production process
Feedback control for stabilizing working point
Fault detection and system health

Spectroscopic System vs. Filter System

What makes the difference ?



Spectroscopic system (EMICON):

Complete wavelength range (monitoring of several species possible)
Separation of lines
Underground subtraction
Ratio technique / actinometry
Multi gas/metal control

Filter system (PEM):

Single wavelength (monitoring of one species only)
No separation of lines
No underground subtraction
Ratio technique not possible
Only single gas/metal control

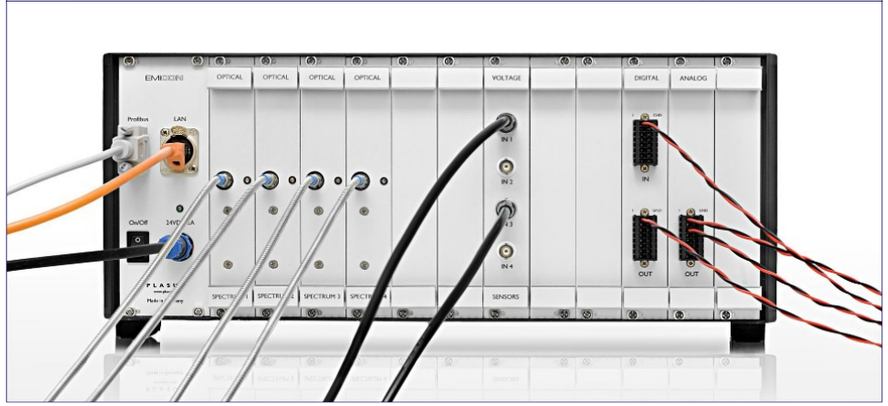
EMICON SA Series

Stand-Alone systems for production lines

Spectroscopic features:
Number of spectrometer channels: 1 – 8
Spectral range of each channel: 200 - 1100 nm
Spectral resolution: approx. 1.5 nm
Temporal resolution: 1 ms – 10 sec

External sensor features:
Number of voltage sensors (0-10V): 2 – 4

Control features:
Number of voltage outputs (0-10V): 4 – 8
Number of PID control channels: 4 – 8
Number of digital IOs (5V/24V): 8 - 16



NEW!

Pulse and HIPIMS features:
Pulse curve inputs: 2 (0-2 V / 0-4 V)
Sampling rate: 40 MHz
Pulse trigger inputs: 2 optical & 1 analog ± 5V

System features:
Integrated processor unit for stand-alone operation
Linux based firmware for 24/7 duty
Administration via LAN from Windows PC

Integration features:
LAN interface (software integration)
Profibus interface (optional)

EMICON MC Series

Multi-Channel systems for R&D applications

Spectroscopic features:
Number of spectrometer channels: 1 – 8
Spectral range of each channel: 200 - 1100 nm
Spectral resolution: approx. 1.5 nm
Temporal resolution: 20 ms – 10 sec

Control features:
Number of voltage outputs (±10V): 4 – 8
Number of PID control channels: 4 – 8
Number of digital IOs (5V): 4 - 8

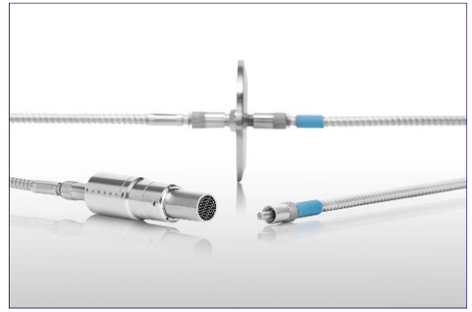
System features:
Windows operation software
USB connection

Housing versions:
10” box for 1-2 spectrometer channels
19” rack box for 1-8 spectrometer channels

- Process analysis, evaluation and optimisation
- Process development and verification
- Process health and fault diagnostics

Optics

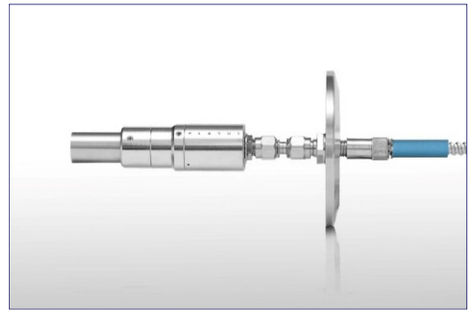
for
In-Vacuum and Ex-Vacuum



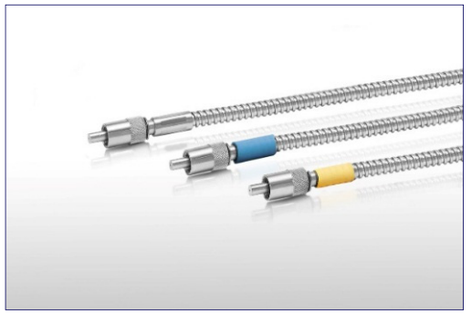
Optical fibers and collimator optics

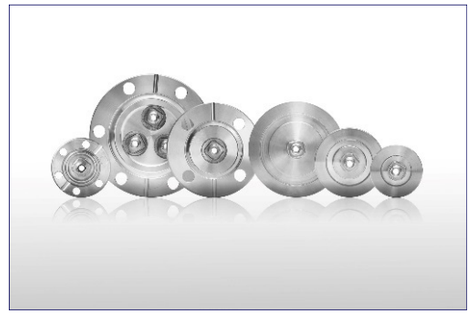
Optical vacuum feedthroughs

Straight and right-angled optical head



Optics with coating protection





SpecLine Software

Offline analysis software for line identification in measured data

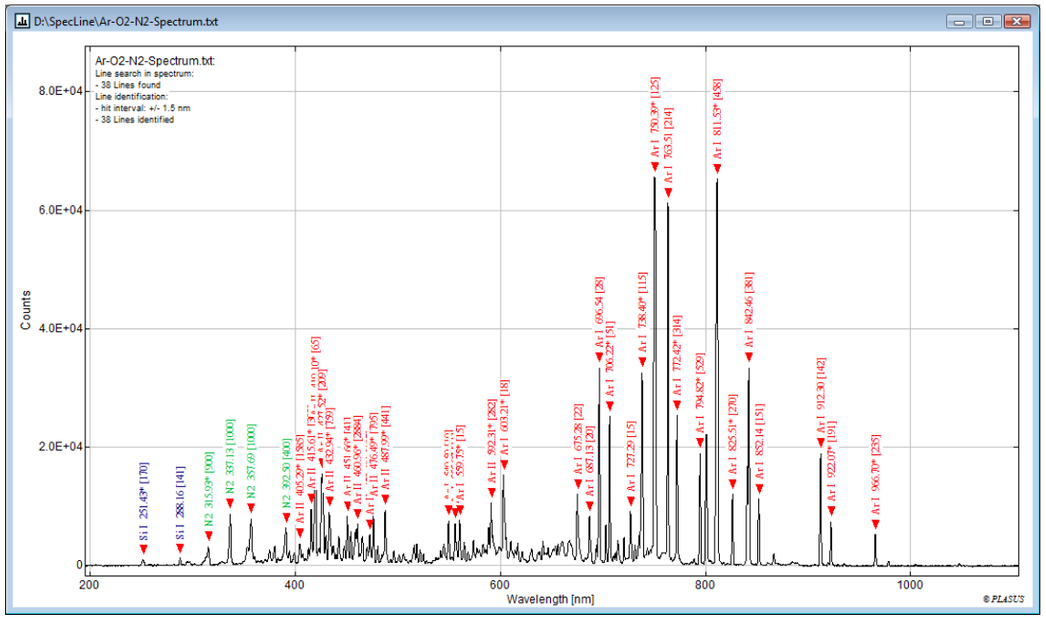
Program features:

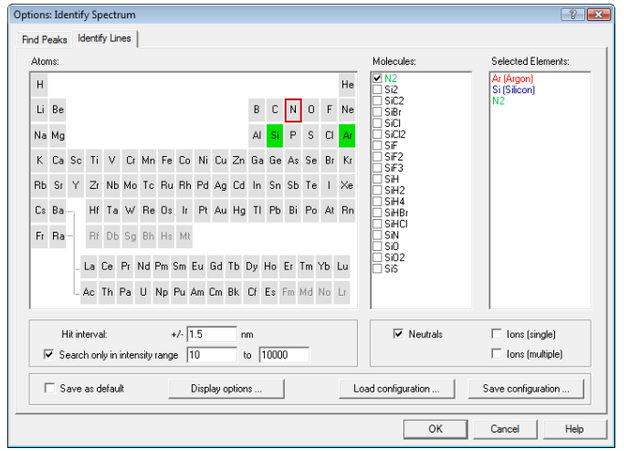
Automatic peak finding and line identification

Detailed information of identified lines: wavelength, energy level, quantum numbers, ...

Comparing spectra form different application

Import data from all common spectroscopic data acquisition systems





SpecLine database:

Atoms: Hydrogen through Einsteinium (Z=1-99)

Molecules: Ag_2 through ZnO, hydrocarbons

Single and multiple ionized ions of atoms and molecules

Wavelength range: 50 nm through 1500 nm

▶ **Worldwide unique spectroscopic analysis software**
for PLASUS systems as well as other spectroscopic systems

Applications

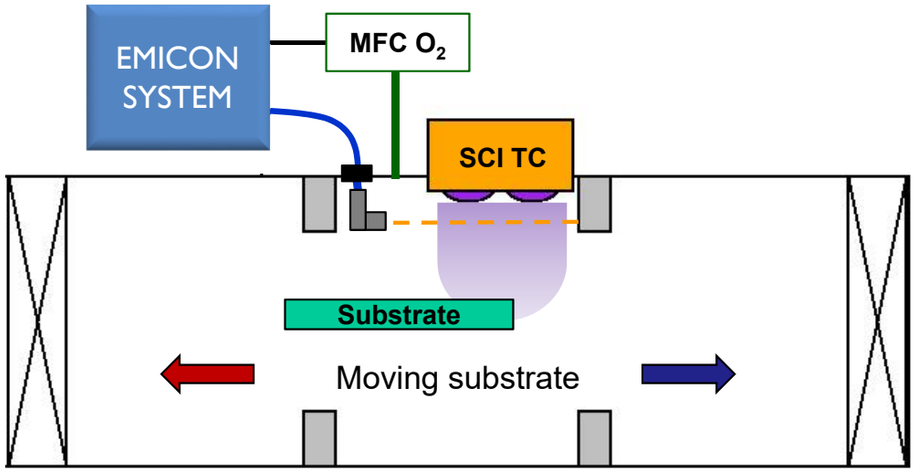
Selected examples

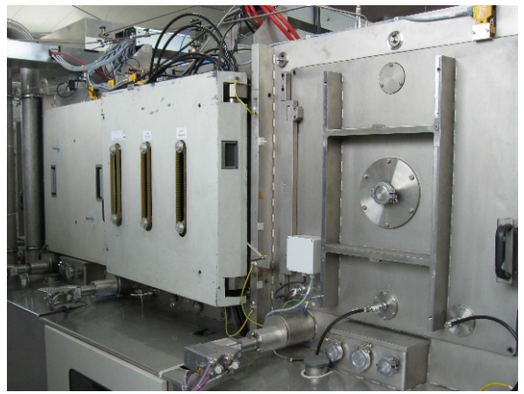
- Sputtering processes	- Closed loop gas flow control in reactive sputtering processes - Large area applications with multi-channel and multi-sensor setup - Multi-chamber application - HIPIMS applications - Confocal multi-target multi-gas sputtering applications
- Film deposition	- Tailoring process runs in PECVD process
- Plasma etching	- Endpoint detection - EPD
- Process tuning	- Optimizing gas flow in industrial ICP application
- System diagnostics	- System health and fault detection
- ATM plasma processes	- Control of process conditions for surface activation by DBD discharge

PECVD, sputtering, HIPIMS, etching, ashing, cleaning ATM, …

Sputtering Processes

Closed loop control of gas flow control





In cooperation with:
robeko

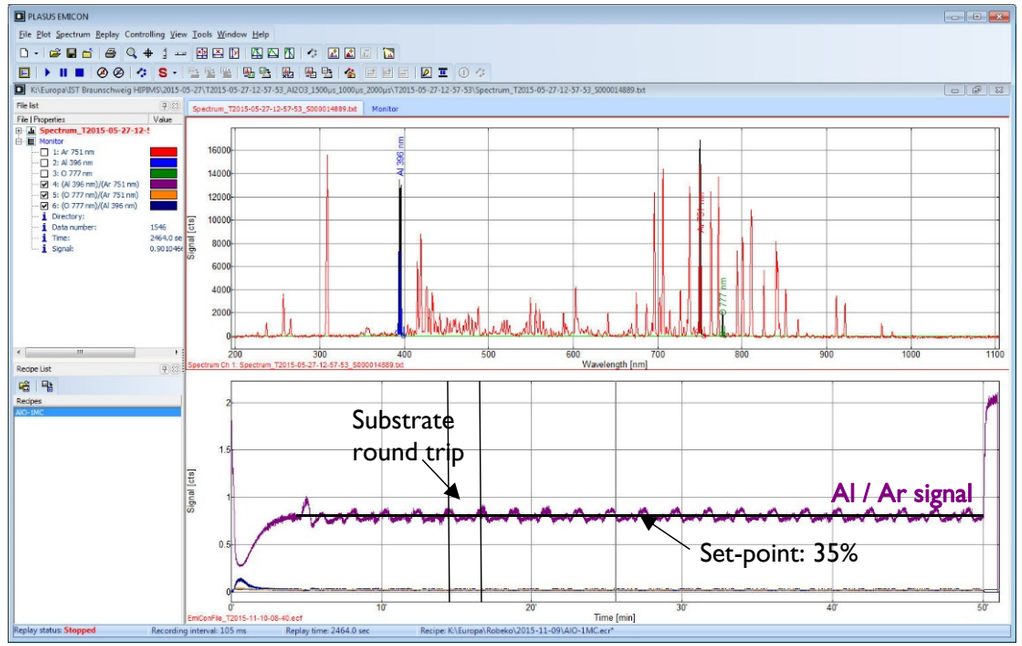
Features:

Stable set-point control at 35%

Refractive index at n = 1.657
Despite periodic oscillation due to substrate movement
→ fast and matched response time

Application:

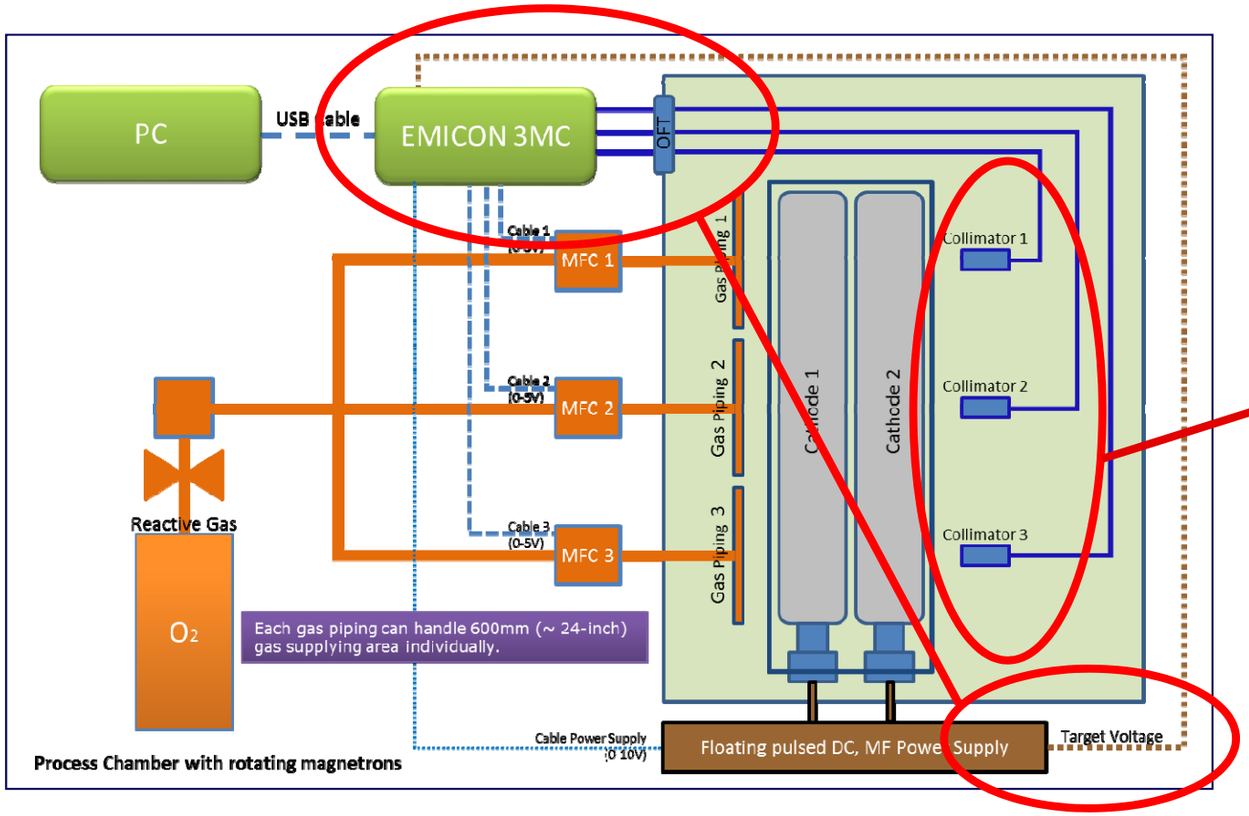
O_2 / Ar plasma on Al target producing Al_2O_3 layer
Moving substrate (back and forth) in front of rotary cathodes
Closed loop control of O_2 gas flow

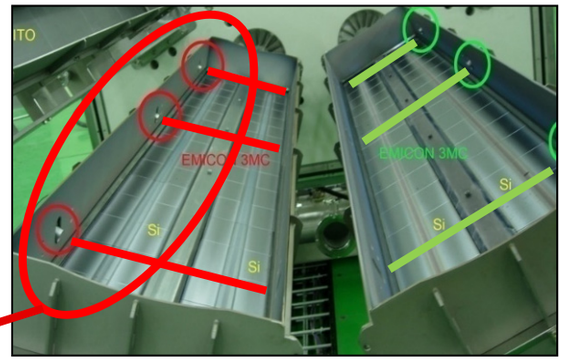


▶ Reliable PID control despite moving substrate

Sputtering Processes

Large area applications with multi-channel and multi-sensor setup





Multi-channel setup
Fast gas flow control for securing layer uniformity

Multi-sensor setup
Slow target voltage control for compensating cathode erosion

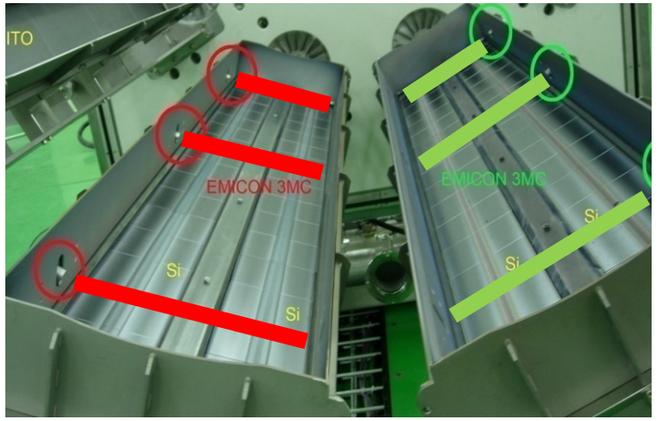
Advanced feedback control techniques:
Closed loop PID for combined sensor inputs
Master and slave configuration
Signal ratio technique

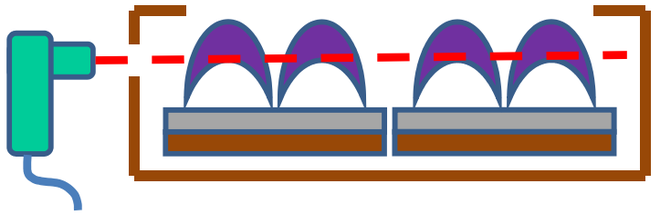
▶ Safe and reliable process control for all current and future sputtering applications

Sputtering Processes

Optics setup

Magnetron targets



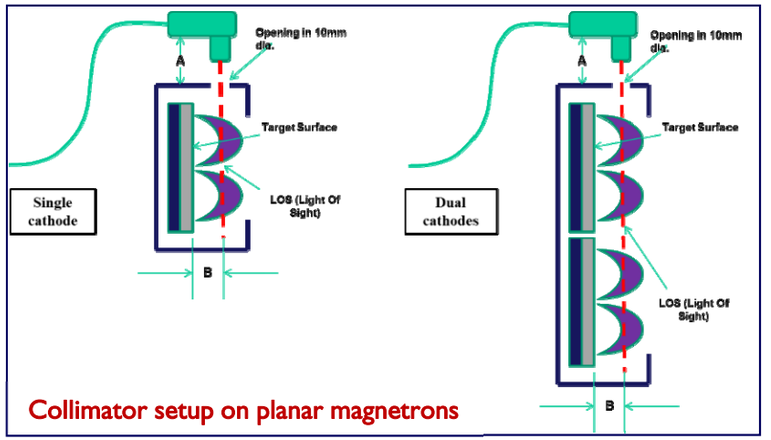


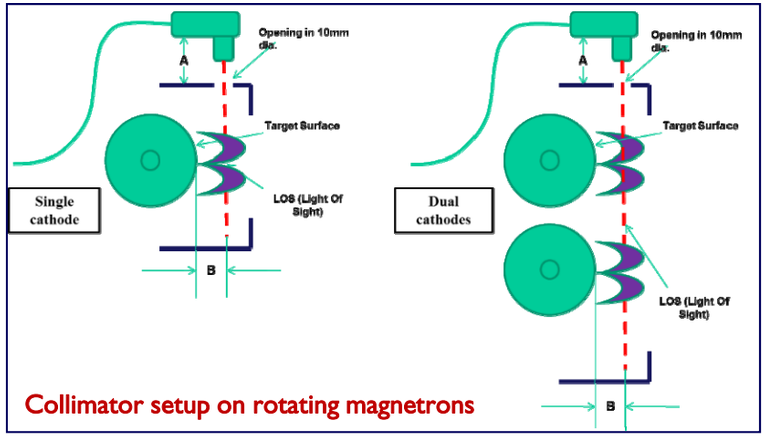
Important:

All light along the line-of sight is detected!

Alignment rules:

- Line-of-sight through similar plasma regions
- Line-of-sight above process surface
- Line-of-sight parallel to process surface

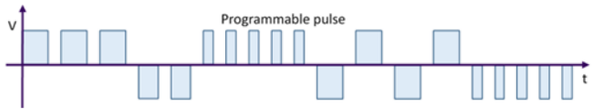


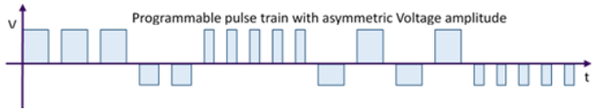


Sputtering Processes

HIPIMS applications

High Power Impulse Magnetron Sputtering

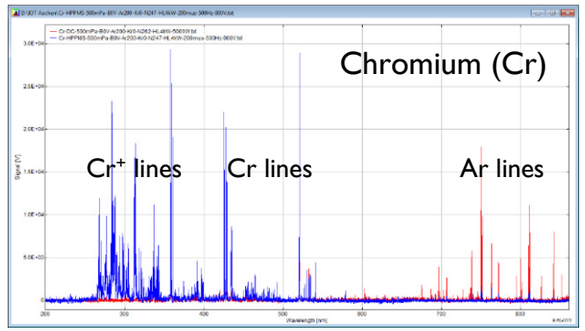


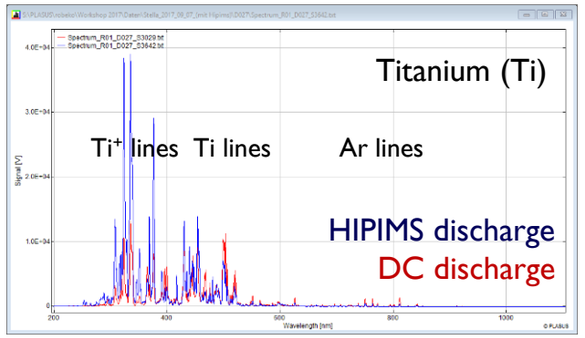


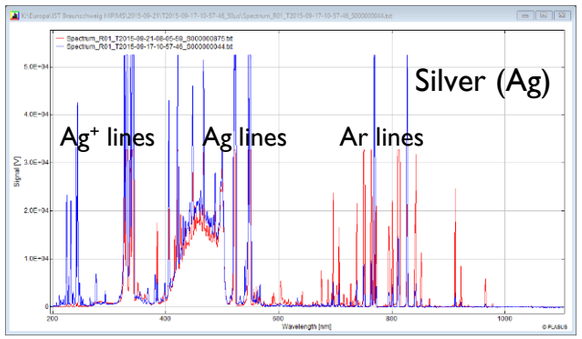
Challenge for reactive processes:
Controlling ion density → layer quality
Controlling reactive gas flow → layer stoichiometry

Spectroscopic plasma monitoring:
Measuring ion density by ion lines
Measuring reactive gas flow by metal lines

▶ **Spectroscopic plasma monitor system is first choice for HIPIMS applications**







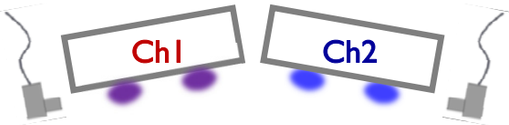
Features:
High power pulses produces metal ions
Average power similar to DC or MF sputtering
New or improved layer properties

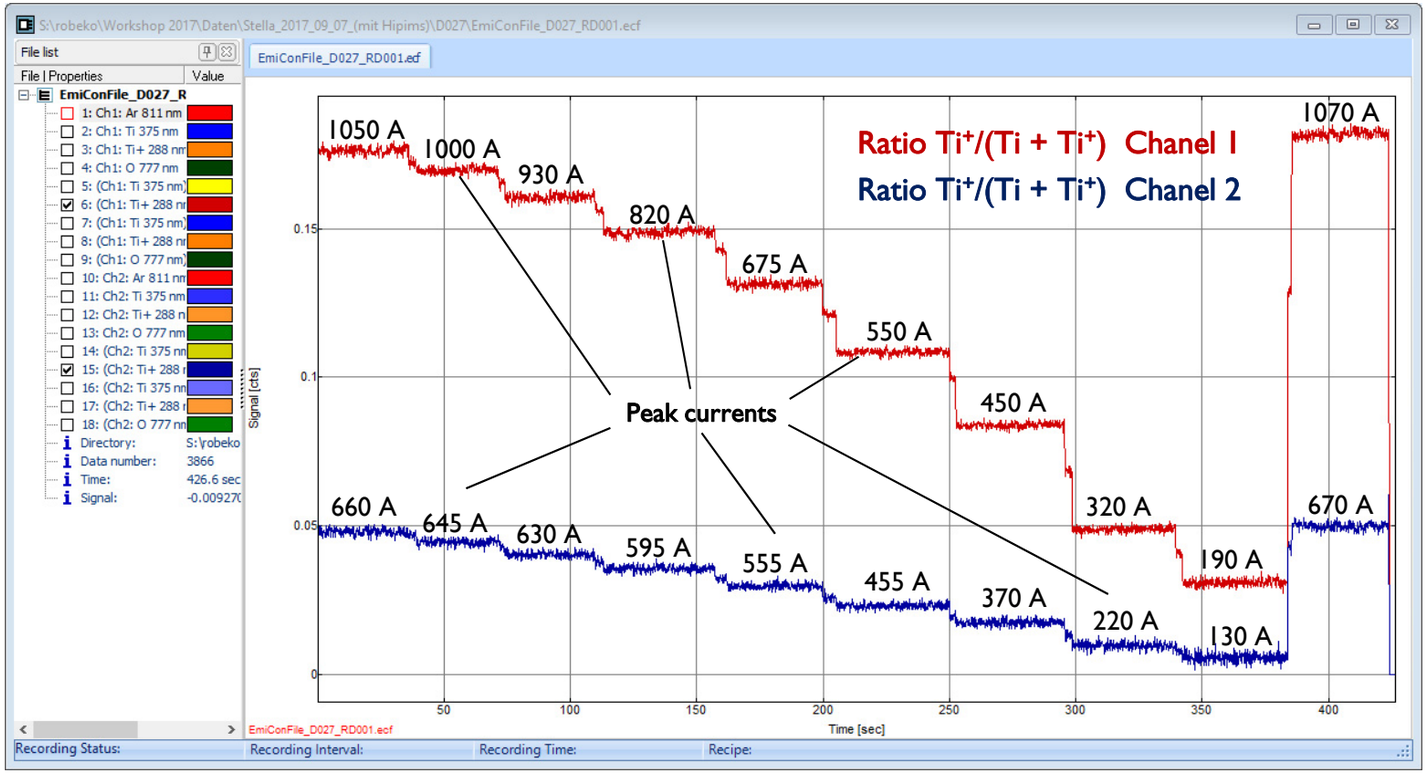
In cooperation with: robeko, MAGPULS, Fraunhofer IST

Supported by: ZIM Zentrales Innovationsprogramm Mittelstand

Metallic HIPIMS Process

Control of ion density





Application:

Ti/Ar metallic HIPIMS plasma
5 kW average power, 50µs pulses
Variation of peak current by varying pulse off time
Monitoring ionization degree $Ti^+/(Ti^+ + Ti)$

Features:

Simultaneous monitoring of ion and neutral density
Real-time signal ratio of ions to neutrals
Different peak currents at targets

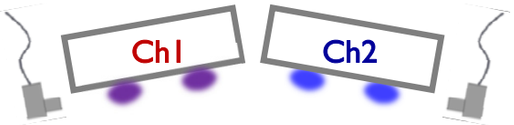
In cooperation with:

robeko

MAGPULS

Reactive HIPIMS Process

Hysteresis effect

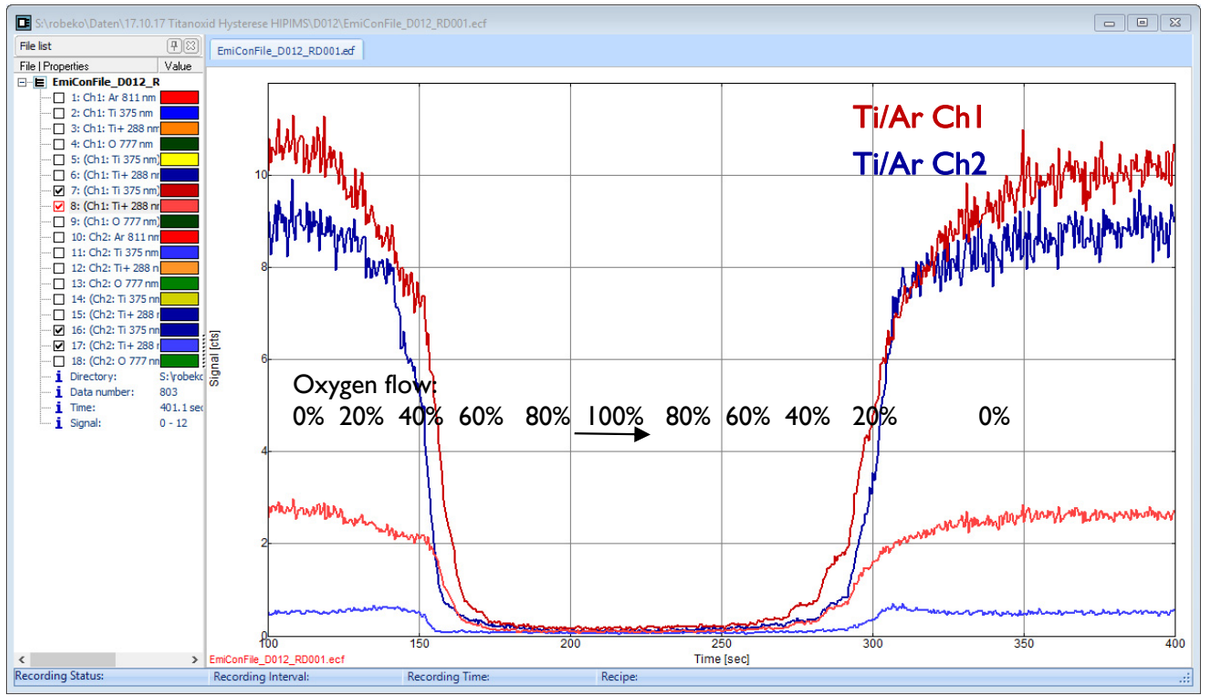


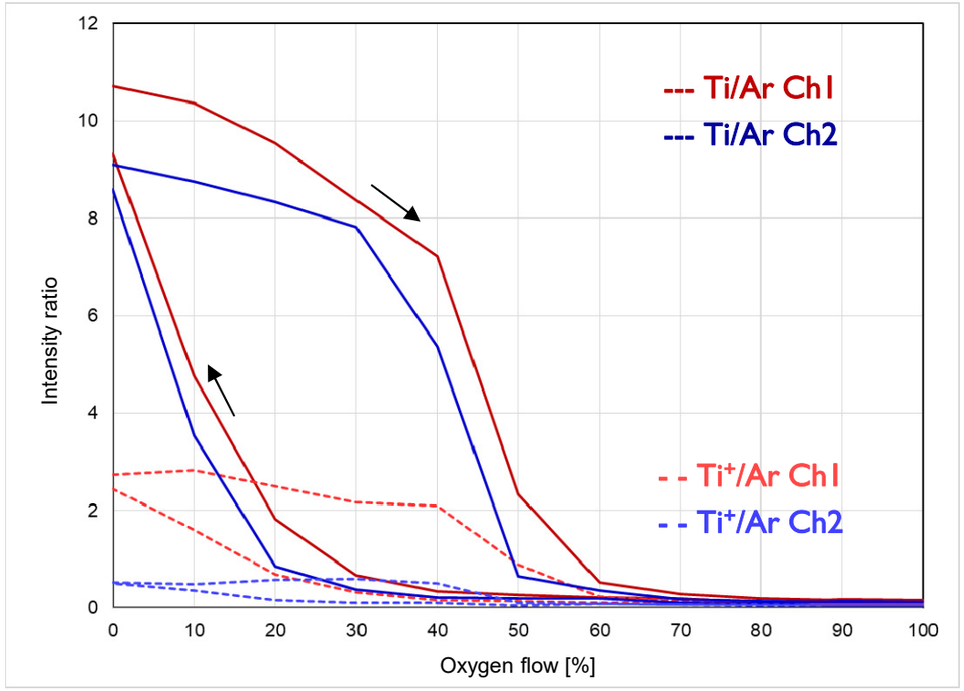
Application:

Ti/O_2/Ar reactive HIPIMS plasma, target size: 90x490 mm
Average power: 3 kW bipolar pulsed, t_{on}: 50 µs, t_{off}: 2000 µs
Pressure controlled at 0.4 Pa: Argon flow:300-250 sccm, Oxygen flow: 0-40 sccm

Features:

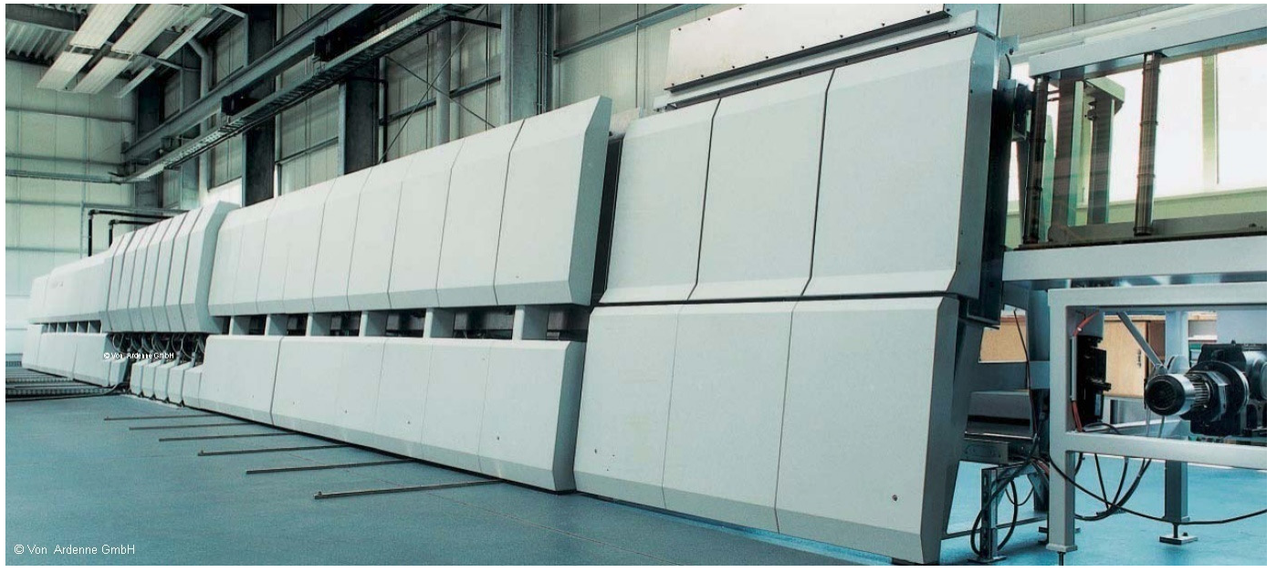
Monitoring signal ratios (eliminating geometry effects)
Hysteresis clearly observed for atoms and ions
Different hysteresis behavior of targets

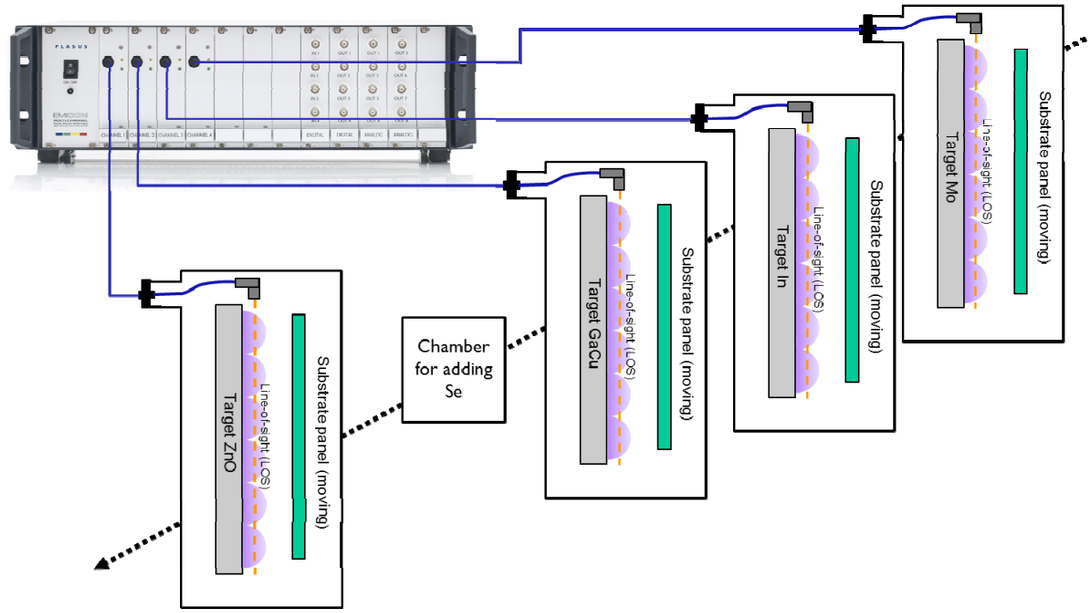




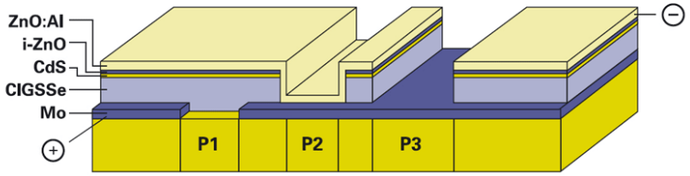
Sputtering Processes

Multi-chamber application in CIGS production line





Layout of CIGSSe-cell

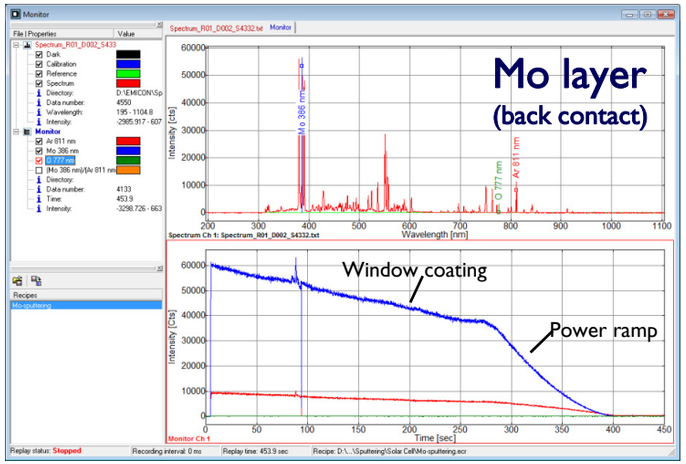


Application:

Inline process for CIGSe cells
Sputtering chamber of each layer
Simultaneous monitoring of each plasma porcess

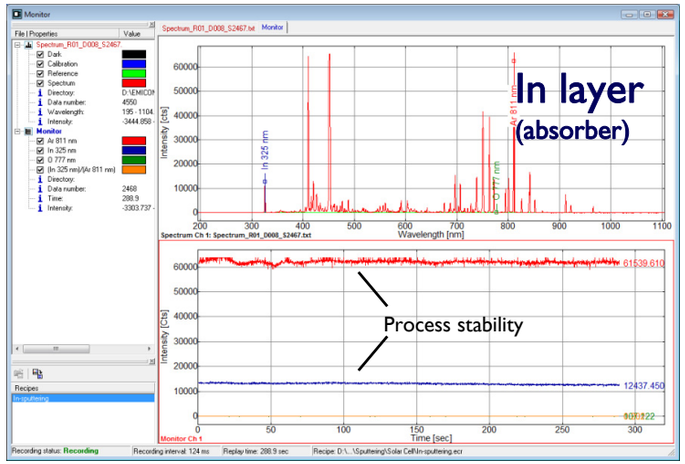
Sputtering Processes

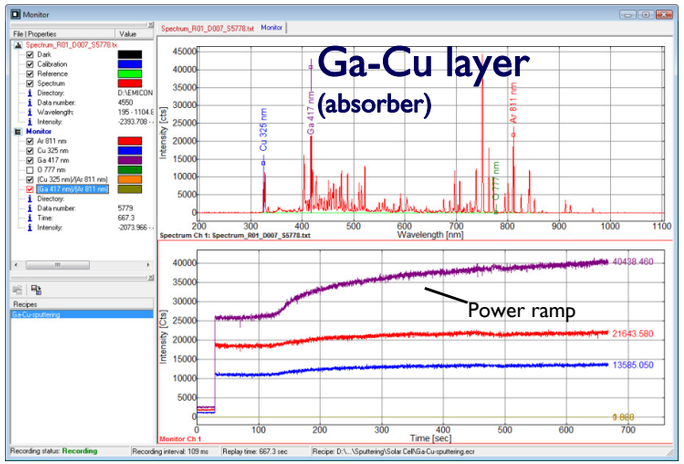
Multi-chamber application in CIGS production line



Features:

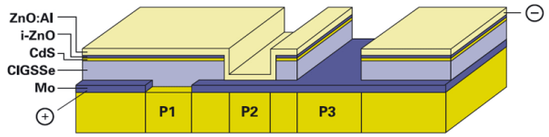
Monitoring of each process step:
- Process stability
- System performance
- Fault detection

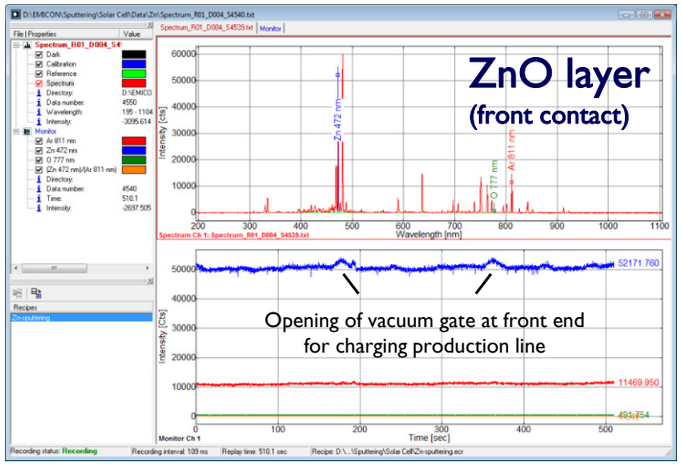




Benefit:

Same EMICON hardware for all chambers
Process selection by software recipe
Complete production control

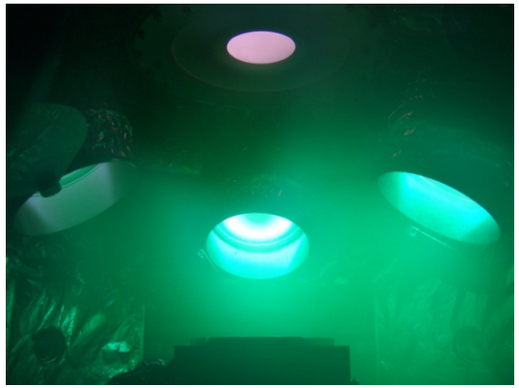


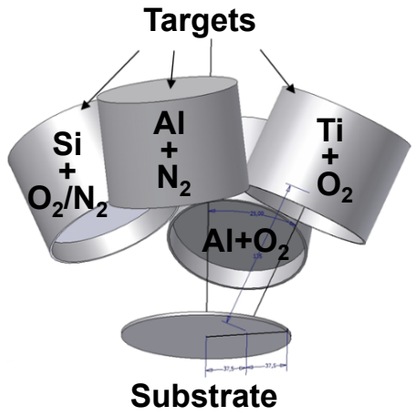


▶ Complete control of inline production line for CIGSSe cells

Sputtering Processes

Confocal multi-target multi-gas sputtering applications





Features:

Each spectrometer channel monitors one target

Monitoring target material, process and reactive gas simultaneously

No signal interference between targets

Same hardware setup for all targets

Benefits:

Process recipe selection by software

Reactive gas flow control for each channel

Control of two reactive gases at one target

Counting for cross-contamination between target

▶ EMICON system is unique and first plasma monitoring tool for confocal multi-target sputtering

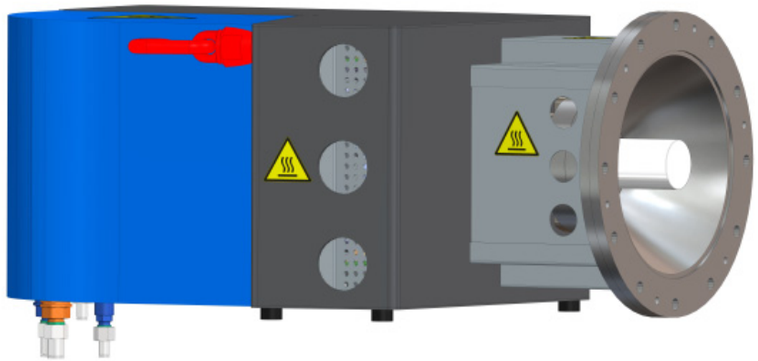
Process Control Systems for Sputtering Applications

Comparison and feature list of different techniques

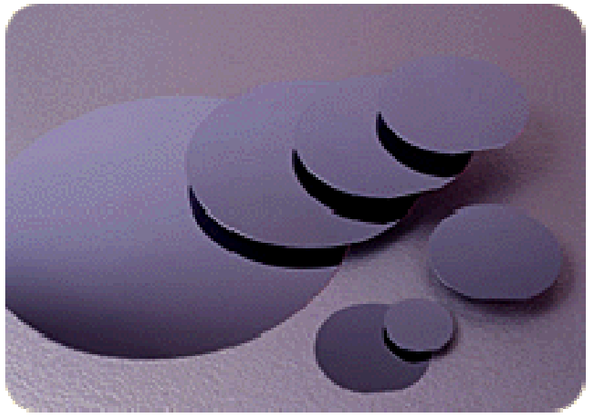
	EMICON	PEM	Lamda	V_{target}
Control of single gas flow: PID control of single reactive gas	✓	✓	✓	✓
Large area targets: Multi-channel system	✓	✓	✓	✗
HIPIMS applications: Simultaneous control of reactive gas and ion density	✓	✗	✓✗	✗
Control of multiple gas flow: Simultaneous PID control of different reactive gases (e.g. O and N)	✓	✗	✗	✗
Control of multi material targets: Control compound targets (z.B. ITO, Al@Cr, …)	✓	✗	✗	✗
Control of power supply: Independent PID control target voltage	✓	✗	✗	✗
Independent control of system conditions: Fault detection and system health (less system-off times)	✓	✗	✗	✗

Film Deposition

Tailoring process runs in PECVD process



MIRO source



Application:

Microwave source MIRO for high rate deposition

Reducing pretreatment time by monitoring transient effects

Optimizing chamber cleaning time by endpoint control

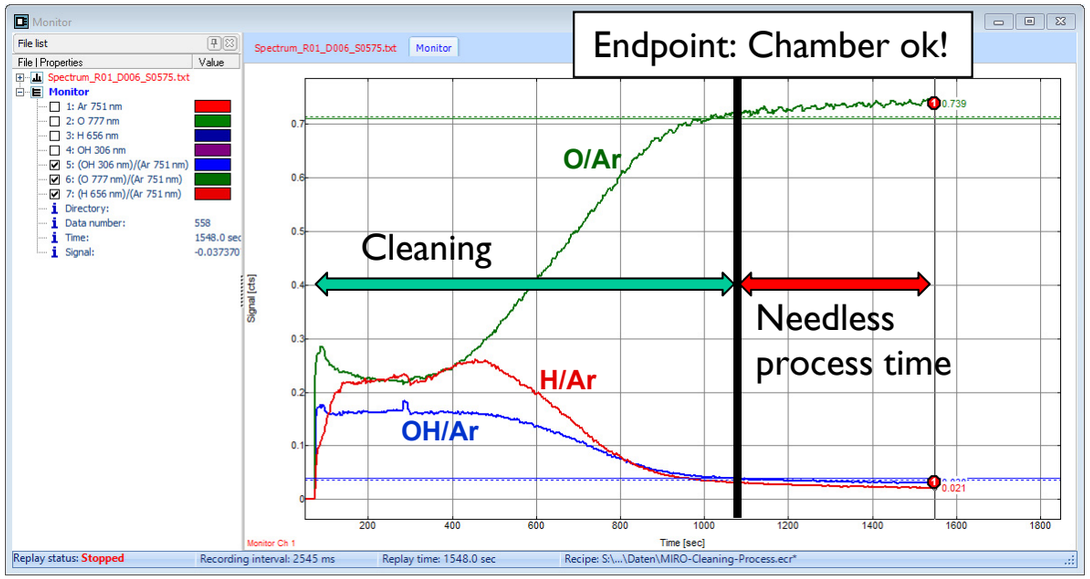
In cooperation with:
robeko

Supported by:
ZIM Zentrales Innovationsprogramm Mittelstand

Film Deposition

Tailoring process runs in PECVD process

Chamber cleaning process



Features and benefits:

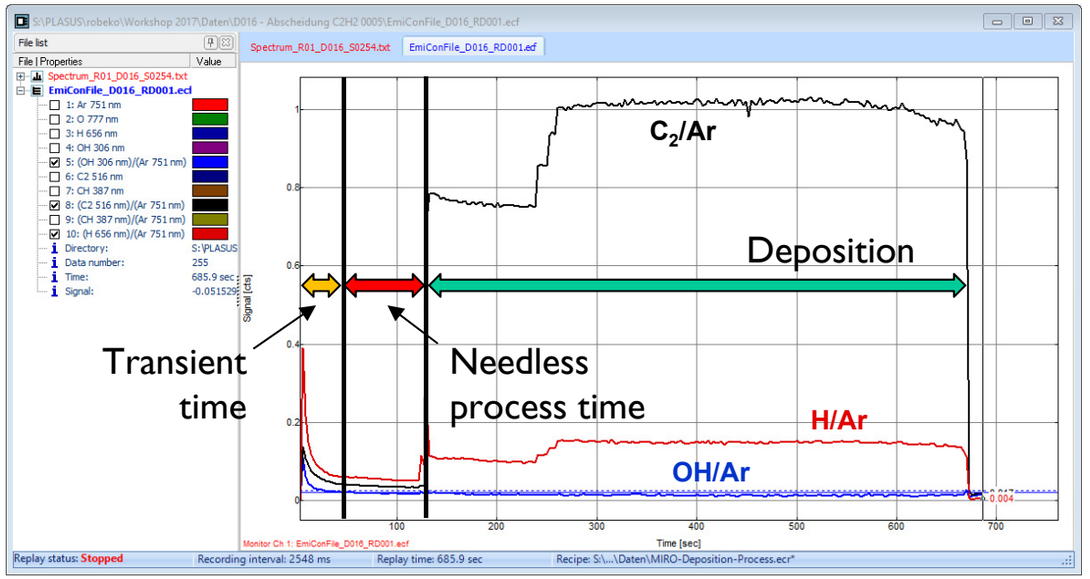
Monitoring etching gas and etch products simultaneously

Defining endpoint conditions for cleaning process

Reducing needless process time

▶ Increasing production up time

Deposition process



Features and benefits:

Monitoring residual moisture in chamber before process start

Securing chamber conditions at process start

Reducing needless process time

▶ Securing batch-to-batch process stability and quality

Plasma Etching Application

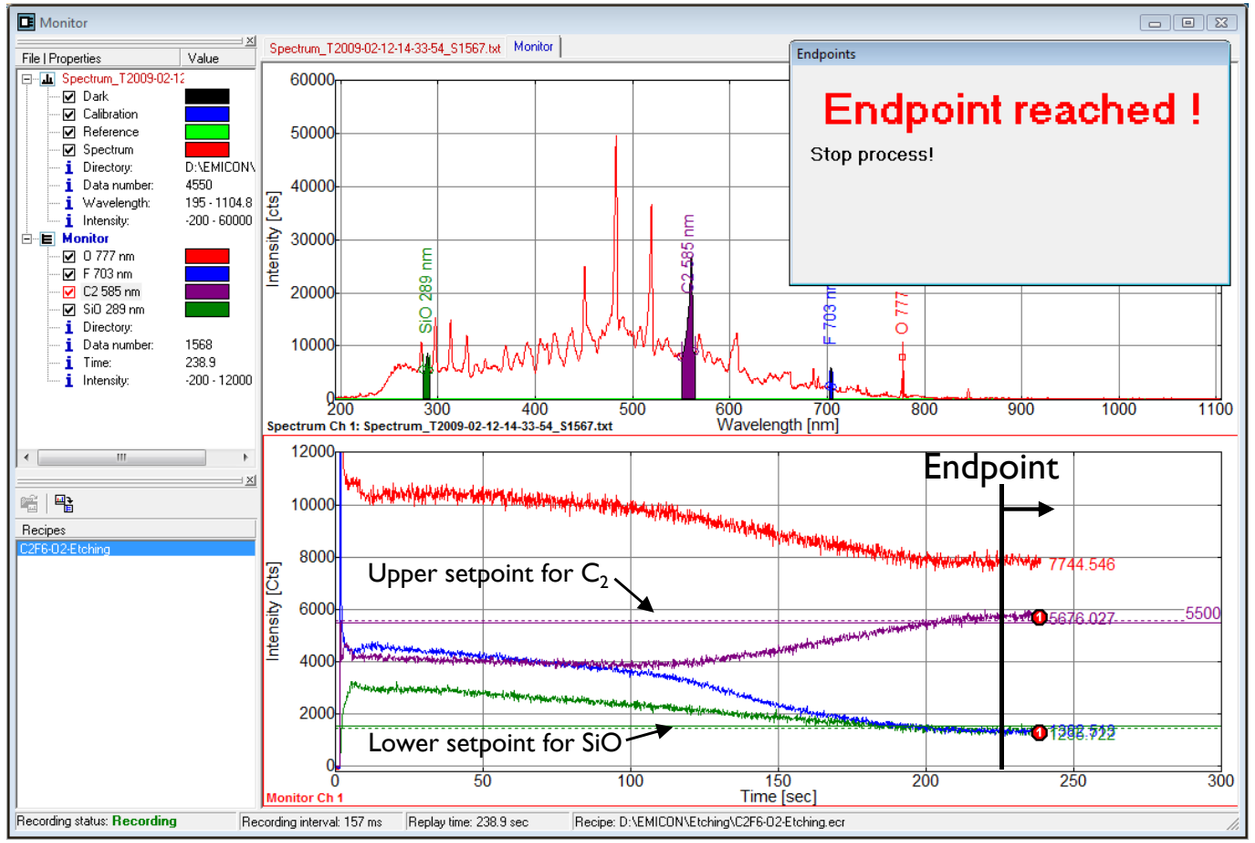
EPD - Endpoint detection

Application:

- Etching of SiO_2 layer on Si substrate
- RF discharge
- C_2F_6 / O_2 etching gas
- detecting of end-point

Features:

- Monitoring of all process relevant plasma species
- Setpoints for each plasma species
- Reliable endpoint detection due to combined setpoints

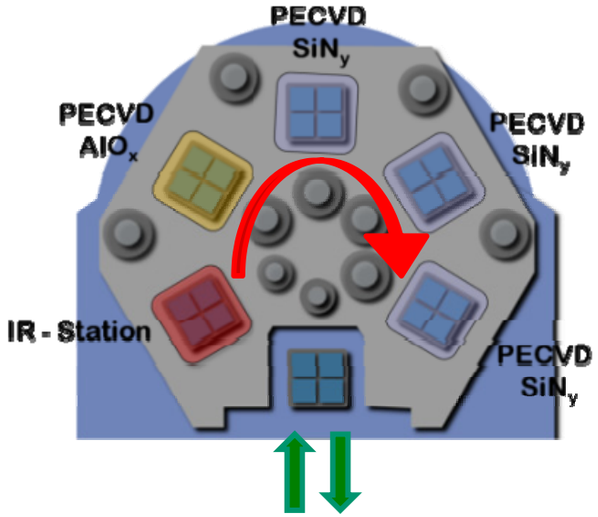


Process tuning and optimization

Optimizing gas flow in industrial ICP application producing passivation layer

SINGULUS Singular XP

6 Stations:
load/unload, heating, 4xPECVD
rotating turntable



Application:
- AlO_x on Si wafer
- ICP source
- Process gases: TMAl, O_2 and Ar
- Process time: about 8 seconds

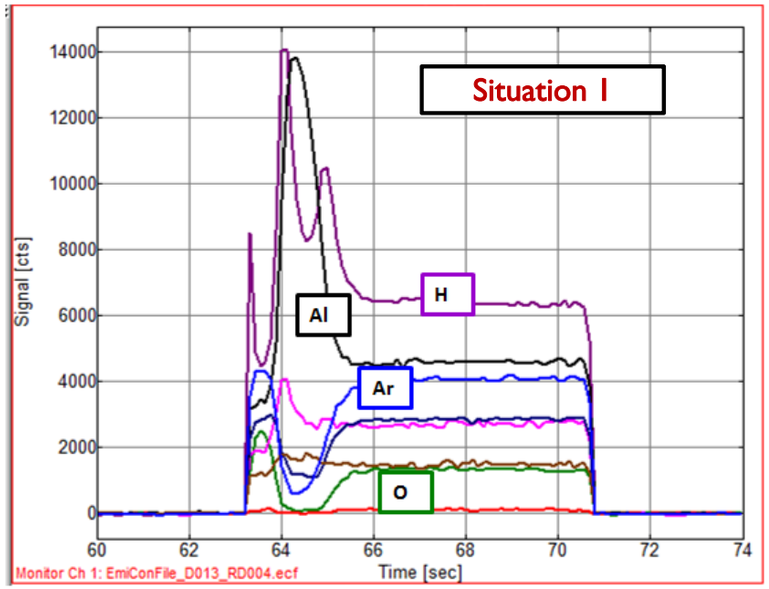
Challenge:
- Reduction of transient time
- Stabilization of process
- Reproducibility of process

In cooperation with:
SINGULUS
Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

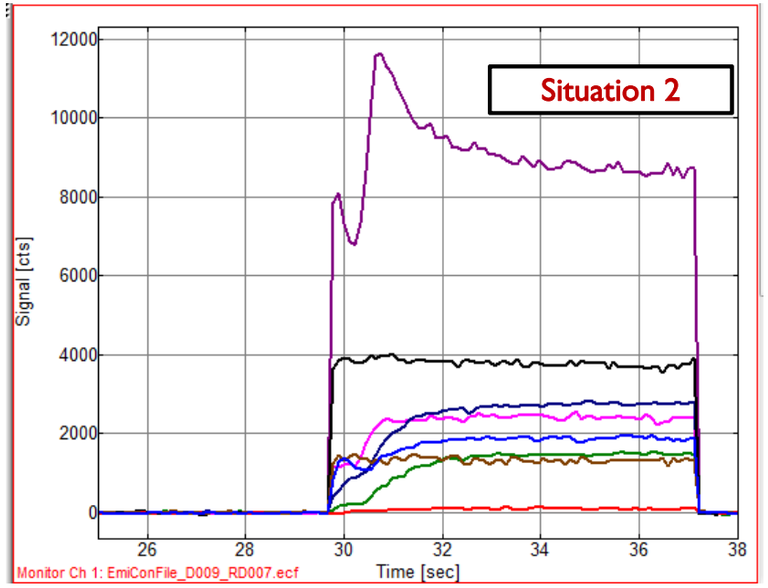
Process tuning and optimization

Optimizing gas flow in industrial ICP application producing passivation layer

Before tuning:



After tuning:



Features:

- Monitoring all plasma species
- Different transient characteristics of plasma species
- Tuning gas inlet time with respect to plasm ignition

Benefit:

- Improving transient characteristics of plasma species
- Faster stabilization of plasma densities
- Reproducible process-to-process characteristics

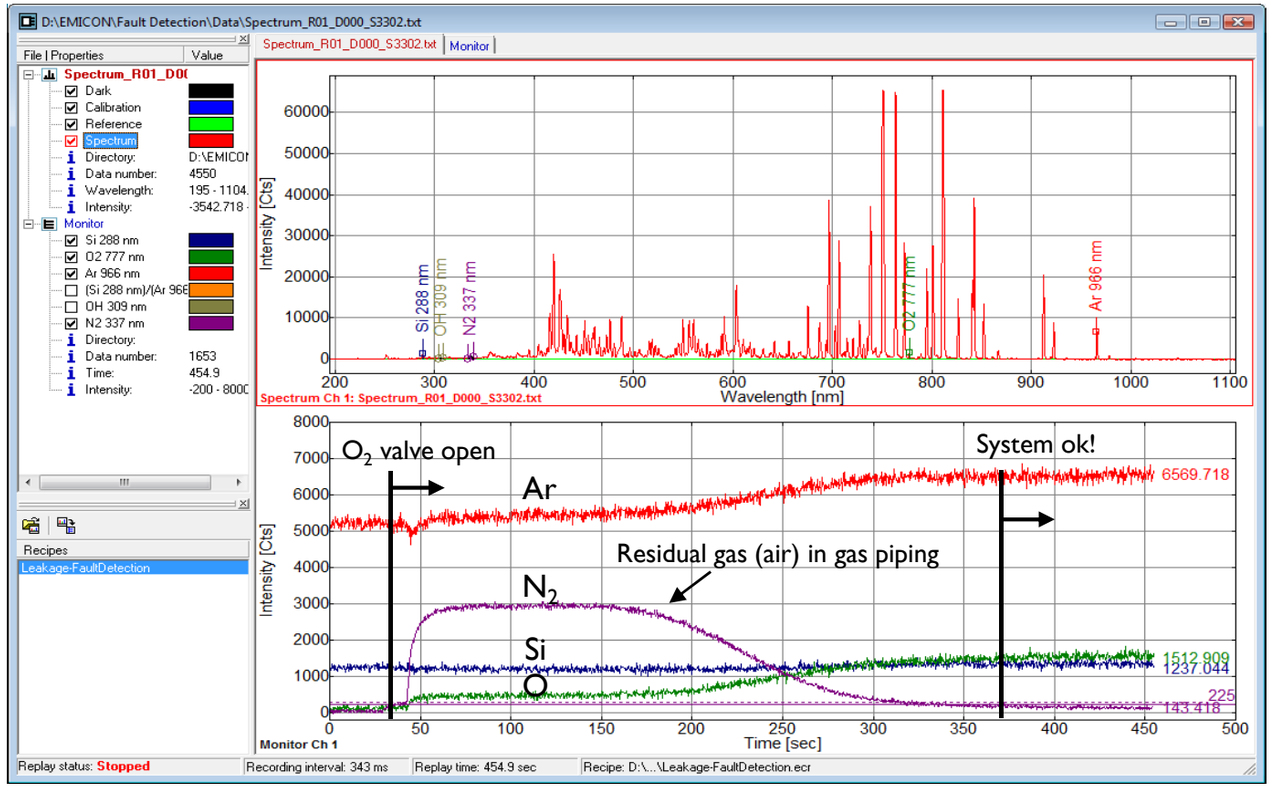
In cooperation with:
SINGULUS

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

System Diagnostics

System health - Fault detection

Example: Residual gas in piping system



Challenge:

Detection of deviation from normal process conditions:

Chamber condition and health

Air leakage, water leakage, gas supply mismatch, …

Gas flow shortage, interruption

Sparking

Features:

Monitoring of:

- N_2 (air leakage)
- OH (water leakage)

Prompt notice of system fault

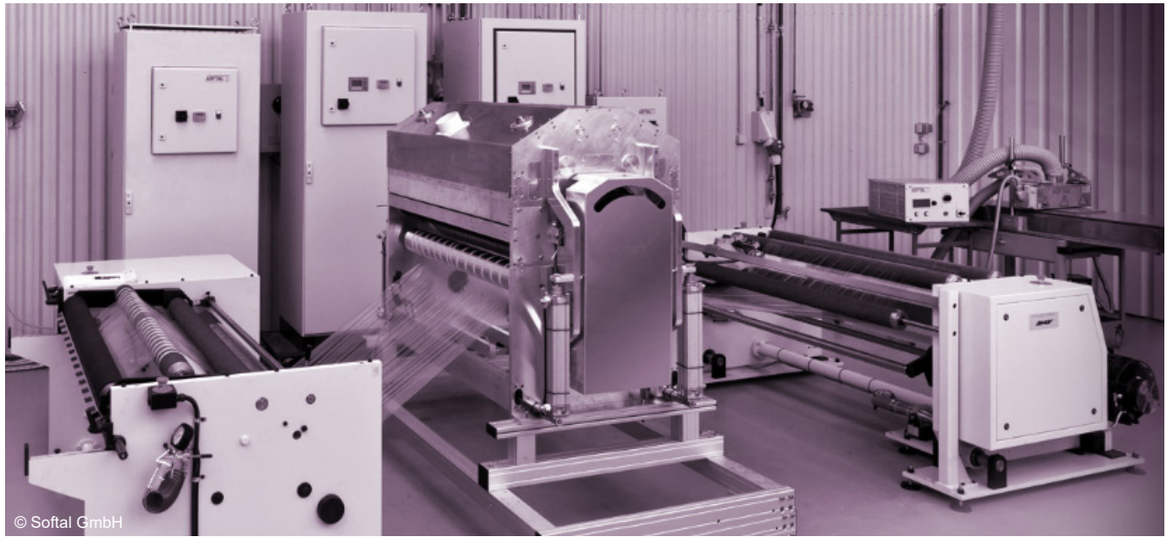
Benefit:

Safeguarding the required plasma conditions

▶ Add-on feature of EMICON system running parallel to process control

Atmospheric (ATM) Plasma Applications

Control of process conditions for surface activation by DBD discharge



Application:

Roll-to-roll unit for rigid films

Activation of film surface for printing, gluing, …

Inline corona/DBD discharge in nitrogen flooded unit

Challenge:

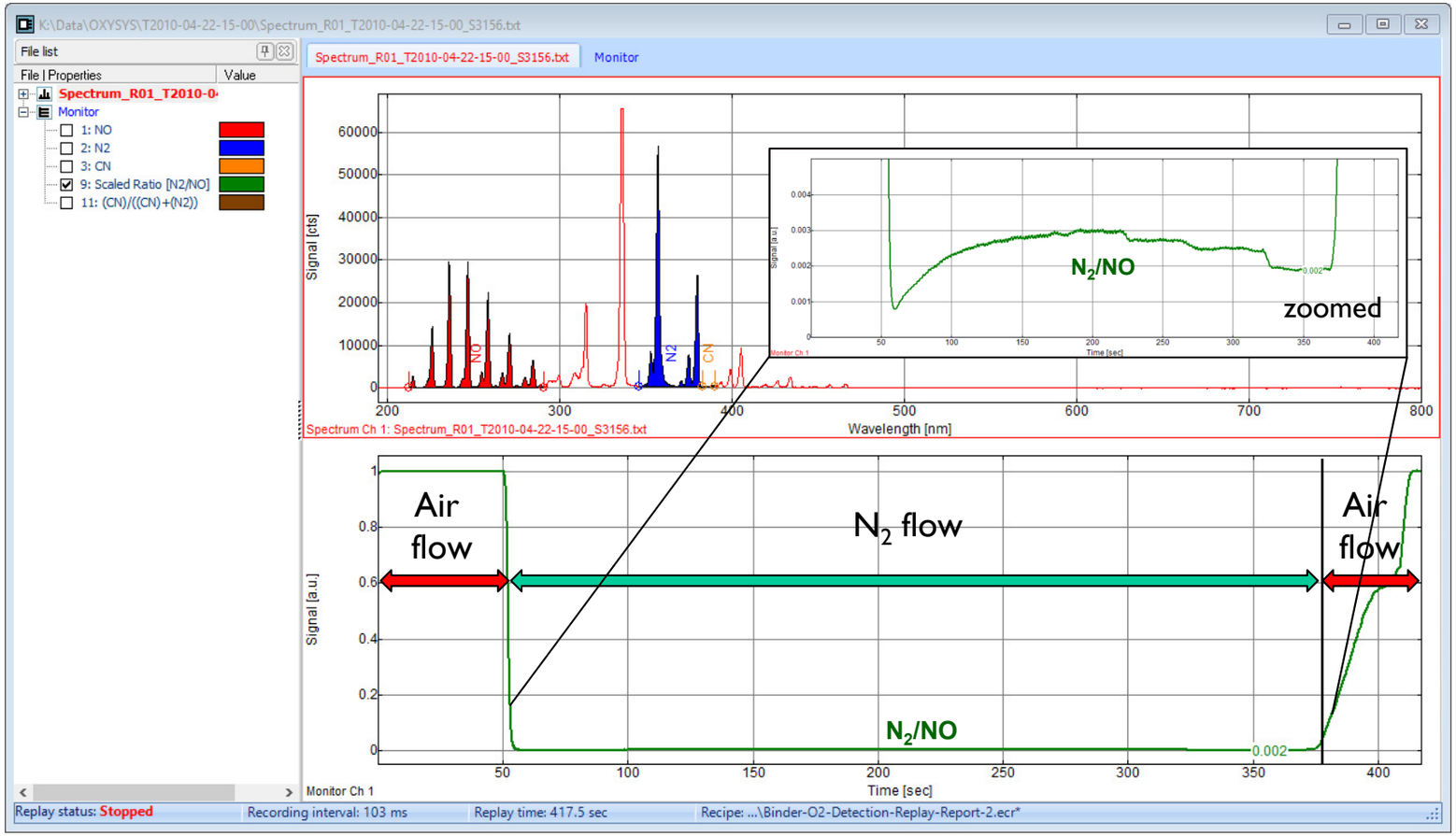
Securing oxygen free treatment

Real-time monitoring of process conditions

Correlation with activation results

Atmospheric (ATM) Plasma Applications

Control of process conditions for surface activation by DBD discharge



Features:

Monitoring of N_2 and NO lines

Ratio N_2/NO very sensitive to residual oxygen

Benefits:

Real-time process monitoring

Correlation with activation results

▶ **Securing production of film activation**

Patent-registered: DE 10 2010 033 787 0

EMICON Systems

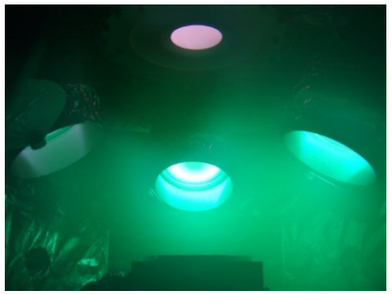
Main Features

Spectral broad-band monitoring:
Advanced plasma process analysis
Process control of multiple gases / target materials
All time information on chamber status

Multi-channel setup:
Multi-process chamber application
Spatial resolution for large area plasmas

Replay mode:
Offline analysis of recorded process data
Design and test of process recipes

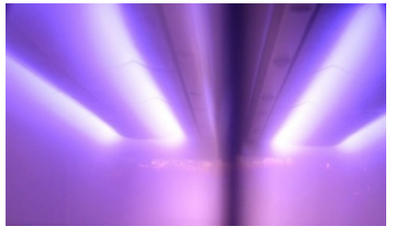
Set-point functions:
End-point detection
Quality control



Advanced PID control:
Reactive magnetron sputtering
Gas flow and/or power control

Recipe manager:
Multi-process switching
Multi-layer processes

Remote control interfaces:
Industrial interfaces for system integration
LAN API, Profibus, digital and analog I/Os, …



Highlights of PLASUS EMICON Plasma Monitor Systems

EMICON SA

+ Spectroscopic easy-to-use plasma monitoring system
+ Multi-channel, stand-alone and multi-sensor feature
+ Powerful and unique functions for process control:
  PID control, endpoint detection, fault detection, system health
+ Optics components for in- and ex-vacuum use
+ Ruggedized equipment for industrial and R&D applications
+ Stand-Alone system for 24/7 use in production lines
+ Retrofitting and upgrading existing OES / PEM systems

EMICON MC

PECVD, sputtering, HIPIMS, etching, ashing, cleaning ATM, …