SVC
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TechCon 2024 Chicago
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Education Program May 4 – May 9
Technology Exhibit May 7 – May 8
67th Annual SVC Technical Conference
May 4 – May 9, 2024
Chicago Hilton,
Chicago, Illinois, USA

The EMICON System - Comprehensive Process Control Combining Complementary Diagnostic Techniques in a Single Unit

Thomas Schütte, Jan-Peter Urbach, Peter Neiß, Marius Radloff, Hokuto Kikuchi, PLASUS GmbH, Mering, Germany

Successful process control of deposition processes requires real-time data from a variety of sensors. Current process control systems cover typically only a single sensor technique resulting in the use of a variety of individual tools to establish a comprehensive process control. This is a drawback for the use in many applications since each control tool requires individual costs and footprint as well as individual resources for system integration and maintenance.

The EMICON system overcomes these issues by combing different sensor techniques for plasma and product in a single system in a modular architecture: multi-channel spectroscopic plasma monitoring with unprecedented time resolution, broadband reflectometry for real-time in-situ layer thickness measurement, electrical pulse curve measurement od voltage and current in HIPIMS and pulsed plasma application, signal input from other sensors like plasma (V-I) probes, lambda probes, ion meter probes, etc. The acquired data from all sensors are processed simultaneously in the EMICON system and can be combined and evaluated for controlling the plasma and product parameters like density of reactive gas species, ion density, layer thickness or color in real-time and simultaneously. This results in a reliable and enhanced production stability and improved product quality at reasonable costs and resources.

This presentation gives an overview of applications where comprehensive process control has already been realized with the EMICON system. Examples of combining the sensor techniques plasma monitoring, electrical measurements and photometric measurements followed by real-time data processing in demanding application such as metallic and reactive sputtering, HIPIMS and PECVD coating processes are presented covering tribological, photovoltaic and architectural glass coating applications.

https://www.svc.org

DOI: https://doi.org/10.14332/svc24.proc.0062

The EMICON System

Comprehensive Process Control combining Complementary Diagnostic Techniques in a Single Unit

Thomas Schütte, Jan-Peter Urbach, Peter Neiß, Marius Radloff, Hokuto Kikuchi
PLASUS GmbH

SVC TechCon 2024
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04.-09. May 2024

Visit us at:
www.plasus.de

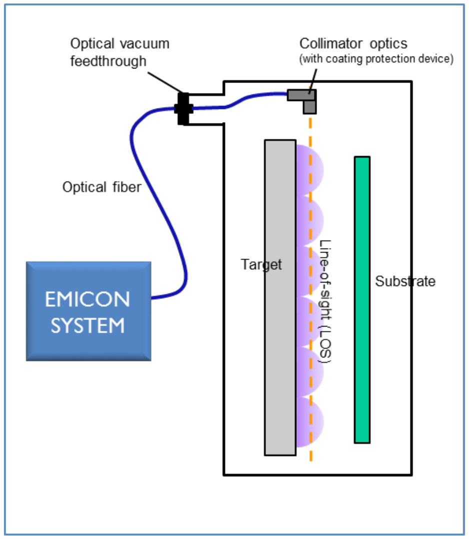
EMICON

Unique Plasma Monitoring and Process Control Systems

Process Control Technology

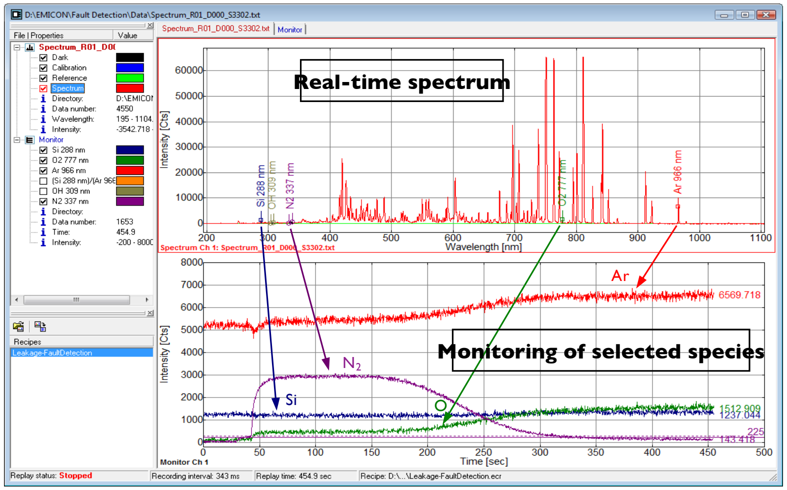
Spectroscopic plasma monitoring

Setup



Easy set-up and mounting
Observation by in-vacuum optics
No disturbance of process

Monitoring technique


D:\EMICON\Fault Detection\Data\Spectrum_R01_D000_S3302.txt

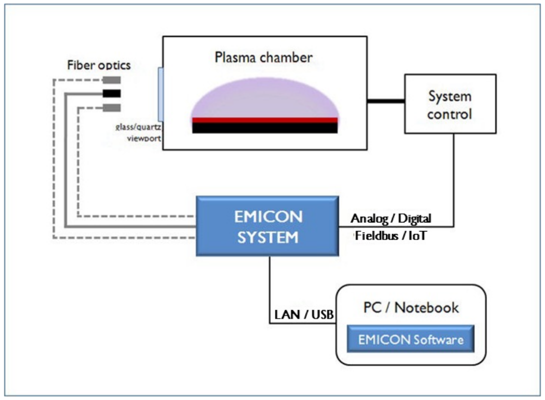
File | Properties	Value
Spectrum_R01_D00	
☑ Dark	
☑ Calibration	
☑ Reference	
☑ Spectrum	
Directory:	D:\EMICON
Data number:	4550
Wavelength:	195 - 1104.
Intensity:	-3542.718
Monitor	
☑ Si 288 nm	
☑ O2 777 nm	
☑ Ar 966 nm	
☐ (Si 288 nm)/(Ar 966	
☐ OH 309 nm	
☑ N2 337 nm	
Directory:	
Data number:	1653
Time:	454.9
Intensity:	-200 - 8000

Recipes
Leakage-FaultDetection

Replay status: Stopped | Recording interval: 343 ms | Replay time: 454.9 sec | Recipe: D:\...\Leakage-FaultDetection.ecr

Measurement of plasma radiation in spectral range 200 – 1100 nm
↳ Selection of process relevant plasma species
↳ Real-time monitoring reveals process conditions

System integration



Feedback to machine and control of plasma process

Applications

Plasma Analysis
Process Monitoring
QA / QC
Reactive Gas Flow Control
Endpoint Detection
Fault Detection

Hard Coatings
Solar Cells
Decorative Coatings
Semiconductor

Coating
Etching
Ashing
Cleaning

PECVD
Sputtering
HIPIMS
Reactive Sputtering
RIE

Magnetron
CCP / ICP
MW / RF
ATM Plasma

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: 50 µs – 10 sec
Recording rate: 15 ms – minutes

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

System features:

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

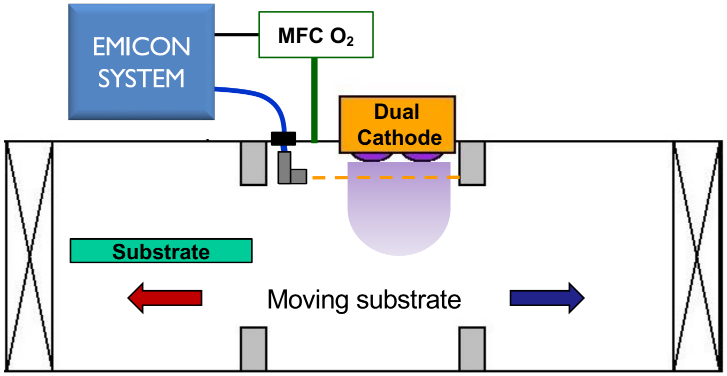
Integration features:

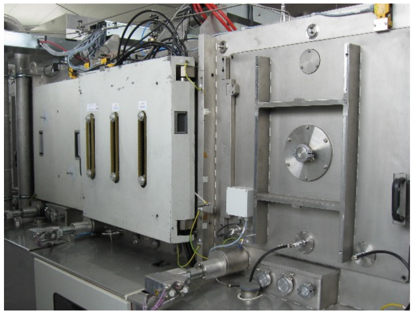
LAN API interface (software integration)
Fieldbus interfaces (SPS integration):
Profibus, Profinet, EtherCAT, EtherNET/IP

The first choice for all standard applications!

EMICON SA Series

Closed loop control of gas flow control in standard sputtering applications





In cooperation with:
robeko

Features:

Stable set-point control at 35%

Refractive index at n = 1.657

Despite periodic oscillation due to substrate movement

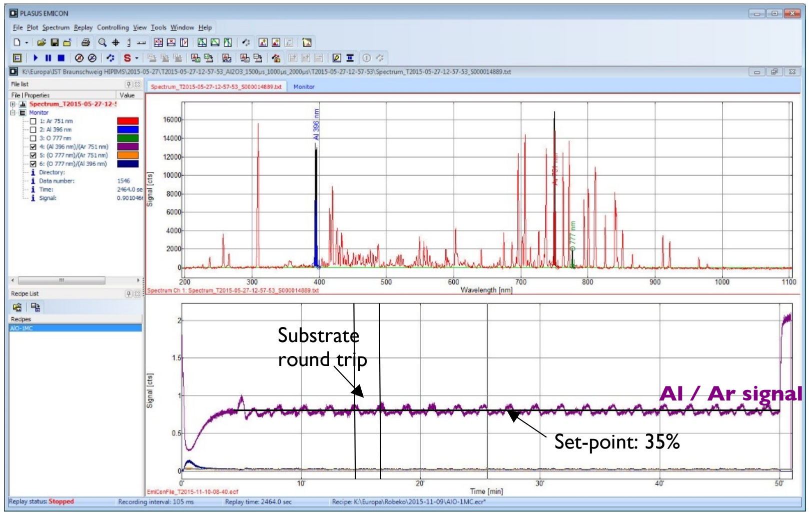
→ fast and matched response time

Application:

O_2 / Ar plasma on Al target producing Al_2O_3 layer

Moving substrate (back and forth) in front of rotary cathodes

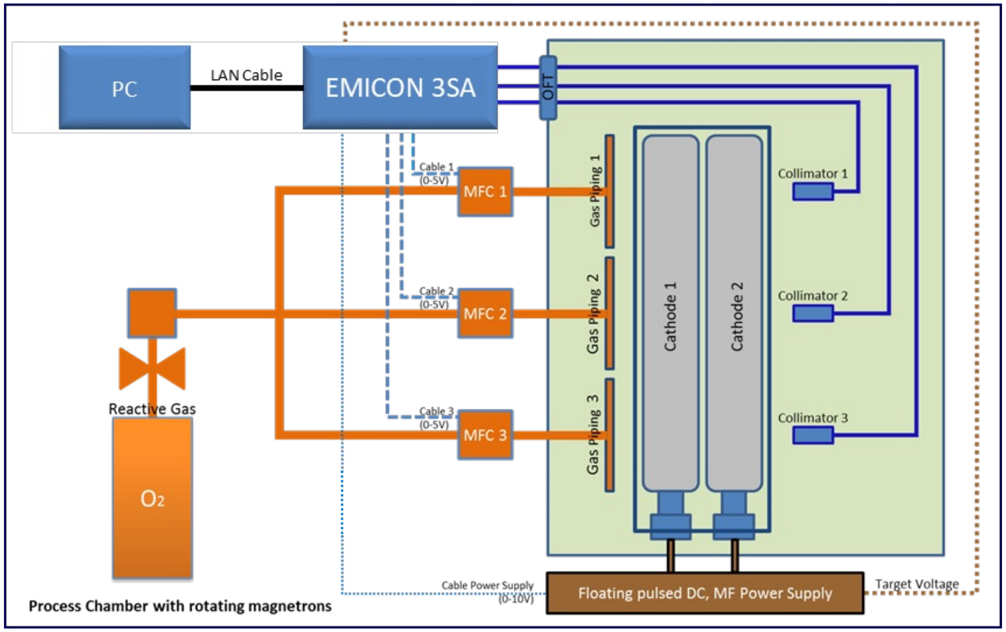
Closed loop control of O_2 gas flow

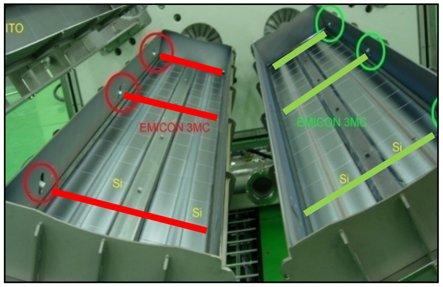


⇒ **Reliable PID control despite moving substrate**

EMICON SA Series

Multi-position setups for large area applications in production lines





Multi-position setup:
Fast gas flow control for securing layer uniformity

Multi-sensor setup:
Moderate 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

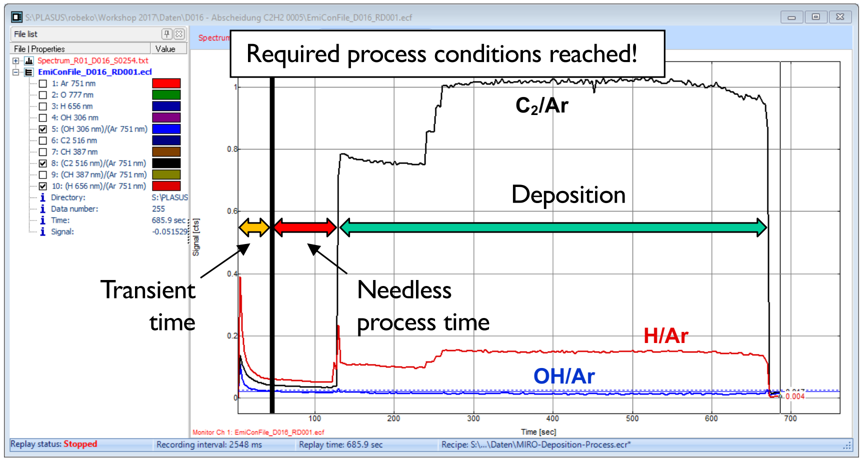
⇒ **Safe and reliable process control for all current and future sputtering applications**

EMICON SA Series

Process readiness and chamber health in batch coater

PECVD process with C_2H_2 / Ar plasma for producing DLC layers

Deposition process: Process readiness and monitoring



S:\PLASUS\robeko\Workshop 2017\Daten\D016 - Abscheidung C2H2 0005\EmiConFile_D016_RD001.ecf

File list

File | Properties	Value
Spectrum_R01_D016_S0254.txt	
EmiConFile_D016_RD001.ecf	
☐ 1: Ar 751 nm	🟥
☐ 2: O 777 nm	🟩
☐ 3: H 656 nm	🟦
☐ 4: OH 306 nm	🟪
☑ 5: (OH 306 nm)/(Ar 751 nm)	🟦
☐ 6: C2 516 nm	🟦
☐ 7: CH 387 nm	🟫
☑ 8: (C2 516 nm)/(Ar 751 nm)	⬛
☐ 9: (CH 387 nm)/(Ar 751 nm)	🟨
☑ 10: (H 656 nm)/(Ar 751 nm)	🟥
Directory:	S:\PLASUS
Data number:	255
Time:	685.9 sec
Signal:	-0.051529

Required process conditions reached!

C_2/Ar

Deposition

Transient time

Needless process time

H/Ar

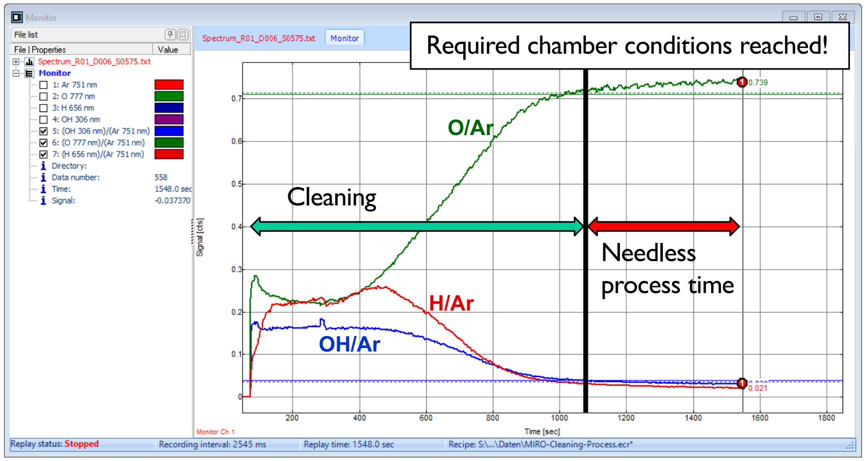
OH/Ar

Replay status: Stopped Recording interval: 2548 ms Replay time: 685.9 sec Recipe: S:\...\Daten\MIRO-Deposition-Process.ecr*

Monitoring residual moisture in chamber before process start
Securing chamber conditions at process start
Reducing needless process time

⇒ Increasing production up time and securing process stability

Chamber cleaning process: Endpoint detection



Monitor

File list

File | Properties	Value
Spectrum_R01_D006_S0575.txt	
Monitor	
☐ 1: Ar 751 nm	🟥
☐ 2: O 777 nm	🟩
☐ 3: H 656 nm	🟦
☐ 4: OH 306 nm	🟪
☑ 5: (OH 306 nm)/(Ar 751 nm)	🟦
☑ 6: (O 777 nm)/(Ar 751 nm)	🟩
☑ 7: (H 656 nm)/(Ar 751 nm)	🟥
Directory:	
Data number:	558
Time:	1548.0 sec
Signal:	-0.037370

Required chamber conditions reached!

O/Ar

Cleaning

Needless process time

H/Ar

OH/Ar

Replay status: Stopped Recording interval: 2545 ms Replay time: 1548.0 sec Recipe: S:\...\Daten\MIRO-Cleaning-Process.ecr*

Monitoring etching gas and etch products simultaneously
Defining endpoint conditions for cleaning process
Reducing needless process time

⇒ Securing batch-to-batch process conditions

In cooperation with:
robeko

EMICON FS Series

Fast Spectral systems for HIPIMS and pulsed 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: **5 µs** – 10 sec
Recording rate: **250 µs** – minutes

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

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 API interface (software integration)
Fieldbus interfaces (SPS integration):
Profibus, Profinet, EtherCAT, EtherNET/IP

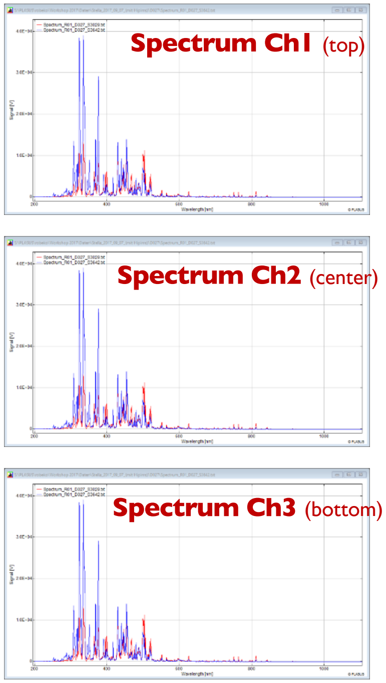
Pulse and HIPIMS features:

Pulse curve inputs: **2 (± 10 V)**
Sampling rate: **40 MHz**
Pulse trigger inputs: **2 optical & 1 analog ± 5V**

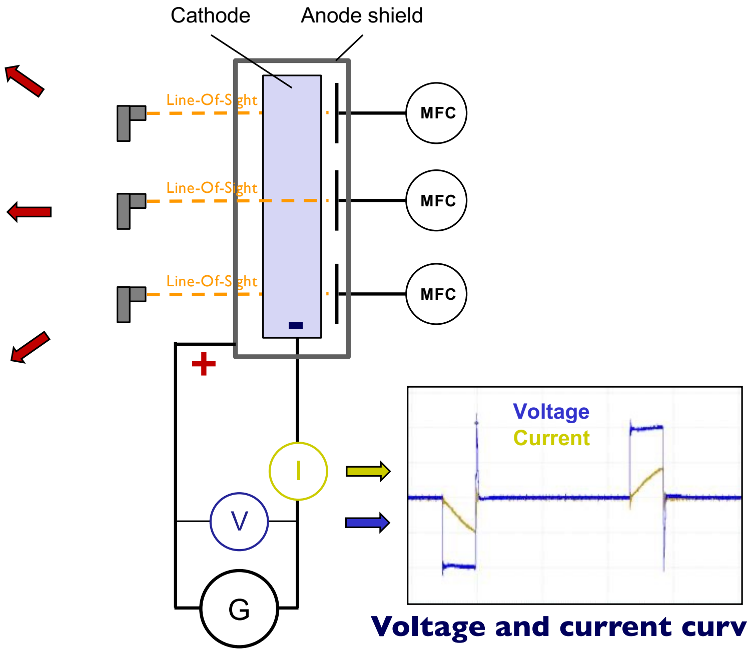
The only choice for pulsed applications and when time resolution is crucial!

EMICON FS Series

Typical setup at industrial HIPIMS coater



Plasma spectrum



Voltage and current curves

Industrial HIPIMS Coater:

Planar cathodes:	15 cm x 65 cm
Target material:	Ti
Process gases:	Ar, O_2
Generator:	Unipolar
Power:	4 kW
Pulse frequency:	500 Hz
Pulse-to-pulse time:	2ms
Pulse ON time:	40 µs
Pulse OFF time:	1960 µs

Spectroscopic sensors:

Position of optics:	top, middle, bottom

Electrical sensors:

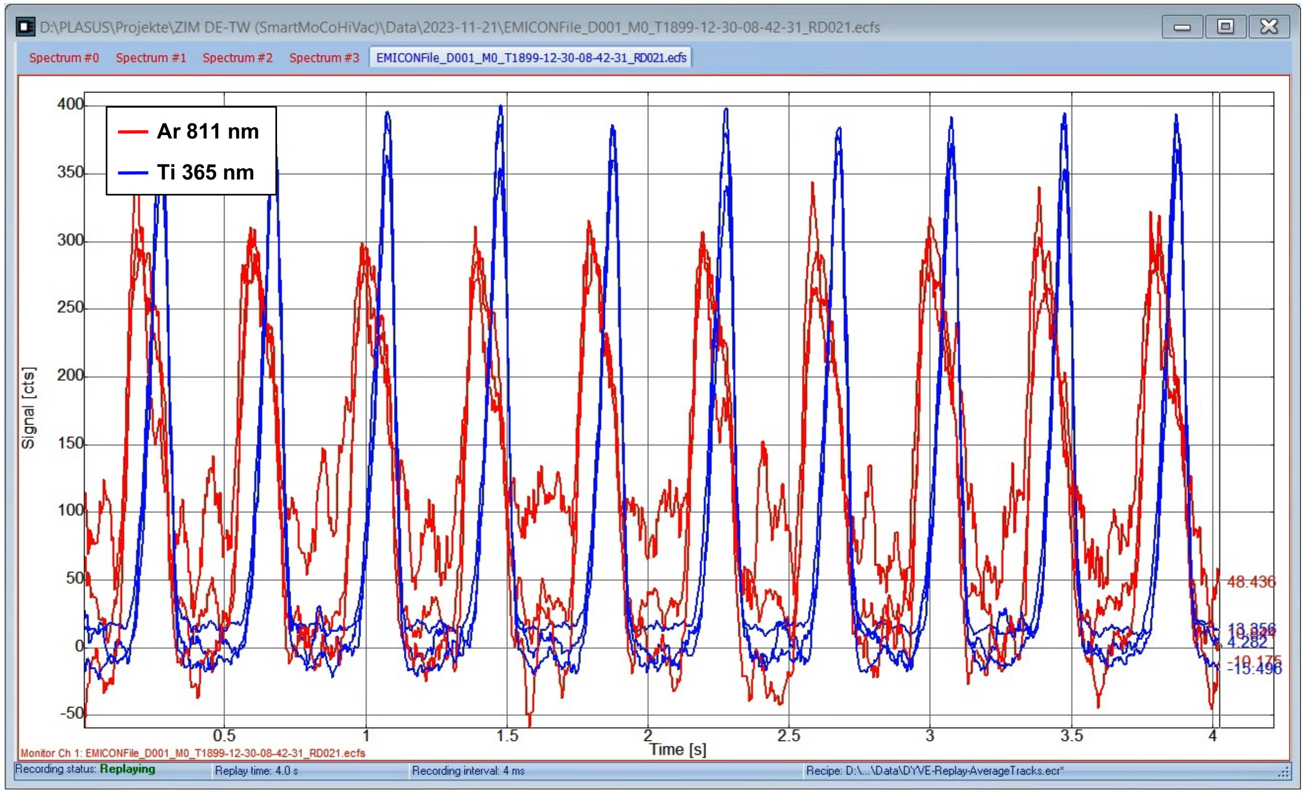
Type of sensor:	voltage curve current curve

In cooperation with:

DAH YOUNG
VACUUM EQUIPMENT CO., LTD.

EMICON FS Series

Real-time monitoring of particle intensities in HIPIMS pulses



D:\PLASUS\Projekte\ZIM DE-TW (SmartMoCoHiVac)\Data\2023-11-21\EMICONFile_D001_M0_T1899-12-30-08-42-31_RD021.ecfs

Monitor Ch 1: EMICONFile_D001_M0_T1899-12-30-08-42-31_RD021.ecfs

Recording status: **Replaying**

Replay time: 4.0 s

Recording interval: 4 ms

Recipe: D:\...\Data\DYVE-Replay-AverageTracks.ecr*

EMICON FS:

Integration time:	6 µs
Recording interval:	2 ms (triggered)
Synchronization:	trigger from generator

Continuous recording:

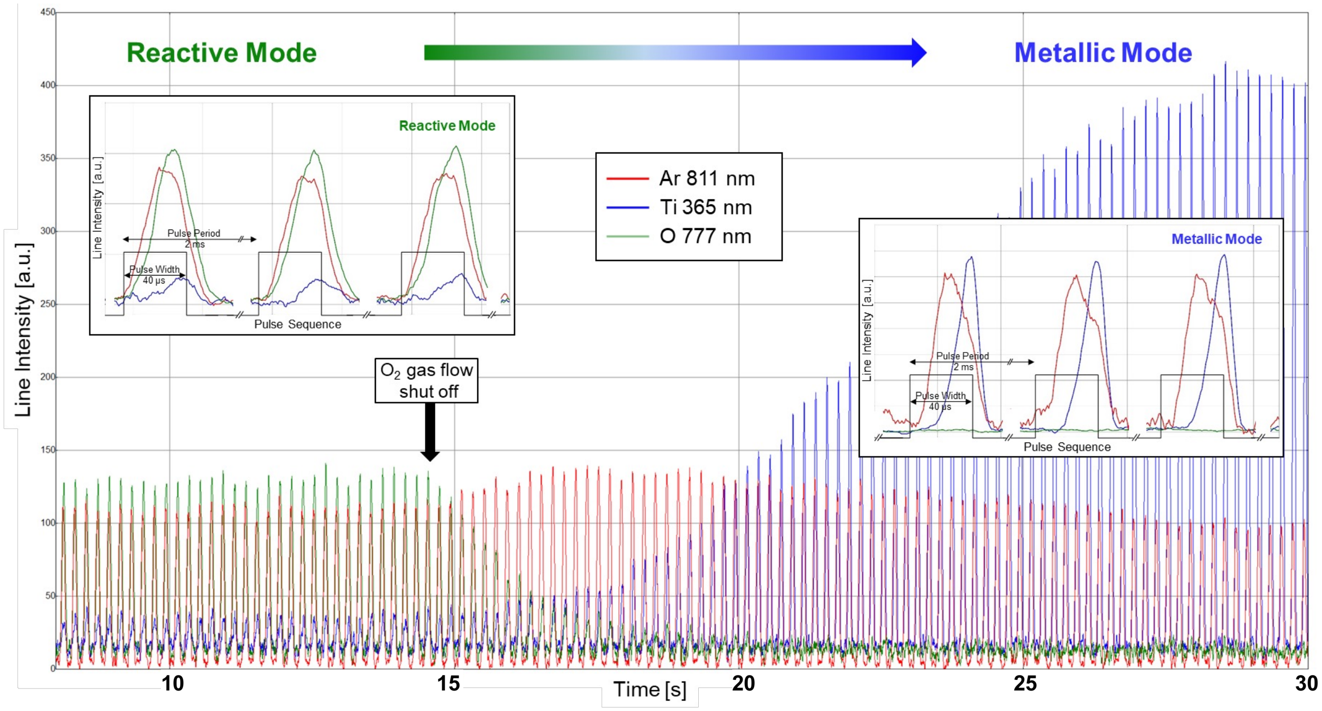
Increasing delay time after each trigger/pulse

Delay step width:	1 µs
Number of steps:	100
Delay range:	0 - 100 µs
Complete pulse:	200 ms
Repetition:	endless loop

EMICON FS Series

Continuous pulse-resolved plasma monitoring

HIPIMS - Transition from Reactive Mode (Oxygen) to Metallic Mode



Benefits:

- ⇒ **Understanding the temporal evolution of the particle densities in HIPIMS pulses**
- ⇒ **Real-time monitoring of density evolution when changing e.g. pulse width, pulse power, pulse shape, pulse-off time, …**
- ⇒ **Real-time synchronisation of substrate biasing, reverse/kick-pulse, …**
- ⇒ **Optimizing process setting for maximum yield**
- ⇒ **Cost effective solution in the price range of standard spectroscopic plasma monitor systems**

More details: HP13, Tue 05/07, 10:10 pm
Thomas Schütte: Continuous Pulse-Resolved Spectroscopic and Electrical Plasma Process Control in HIPIMS Applications

EMICON LC Module

Layer Control module for in-situ measurement of layer properties

Spectroscopic features:

Number of spectrometer channels: 1 – 8
Spectral range of each channel: 200 - 1100 nm
Spectral resolution: approx. 1.5 nm
Temporal resolution: 50 µs – 10 sec
Recording rate: 15 ms – minutes

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

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 API interface (software integration)
Fieldbus interfaces (SPS integration):
Profibus, Profinet, EtherCAT, EtherNET/IP

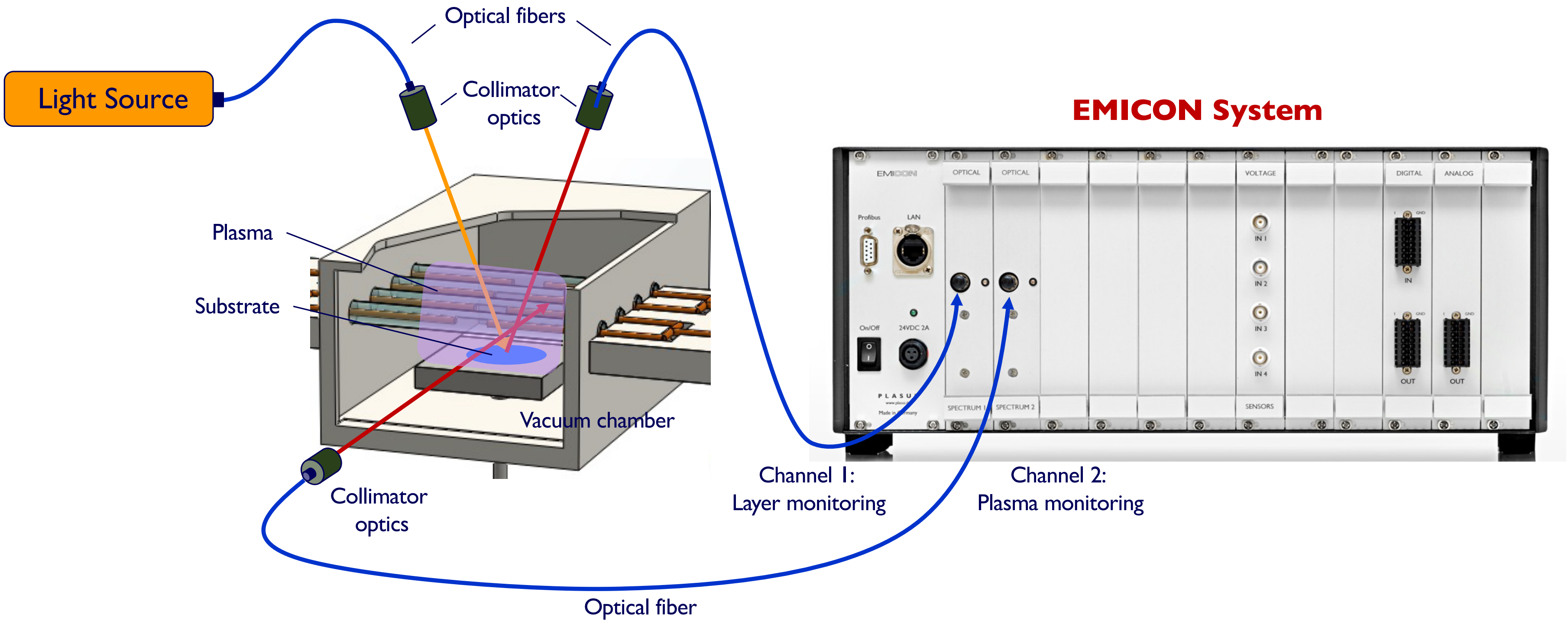
Layer control features:

Type of measurement: **reflection & transmission**
Layer properties: **thickness, roughness, color**
Methodology: **real-time fitting using n&k**

The first choice for demanding film growth applications!

EMICON LC Module

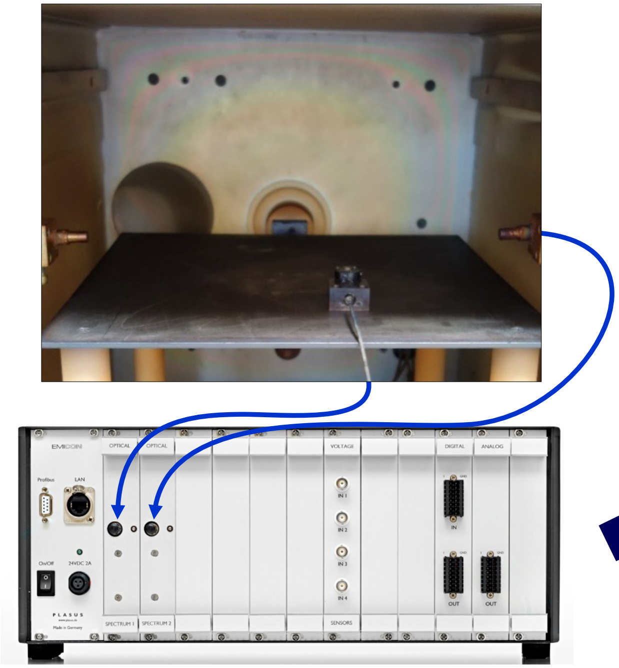
Adding in-situ measurement of layer properties

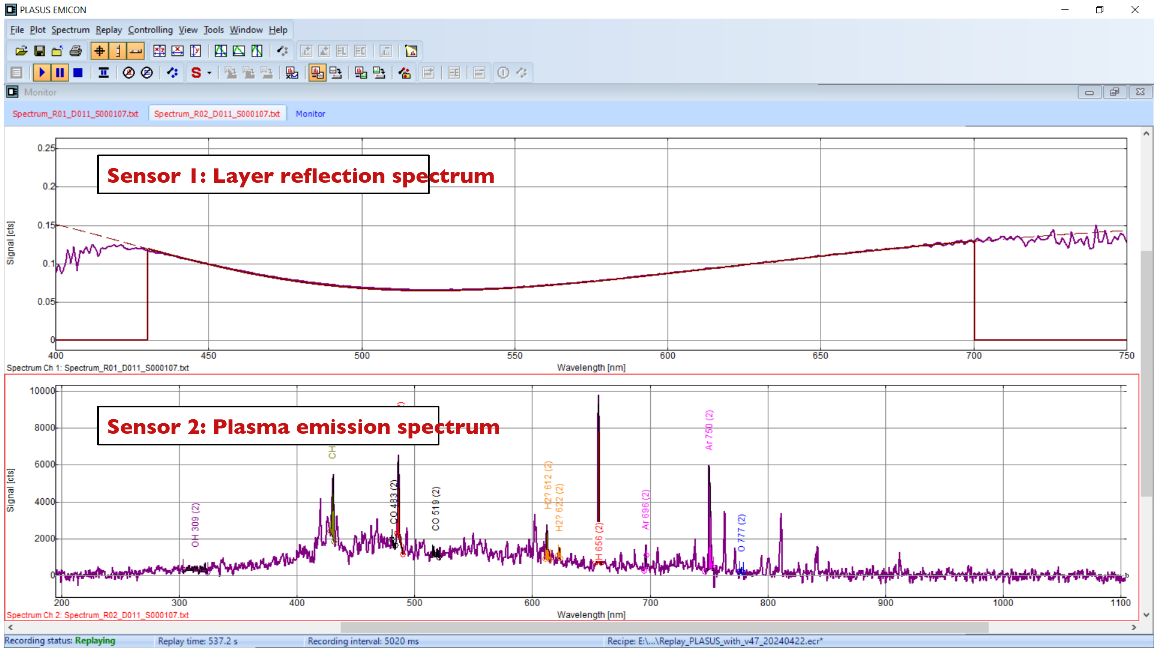


EMICON Series with LC Module

Simultaneous measurement of plasma process and layer properties

Example: PECVD process for SiO_x layers





Sensor 1: Layer reflection spectrum

Spectrum Ch 1: Spectrum_R01_D011_S000107.txt

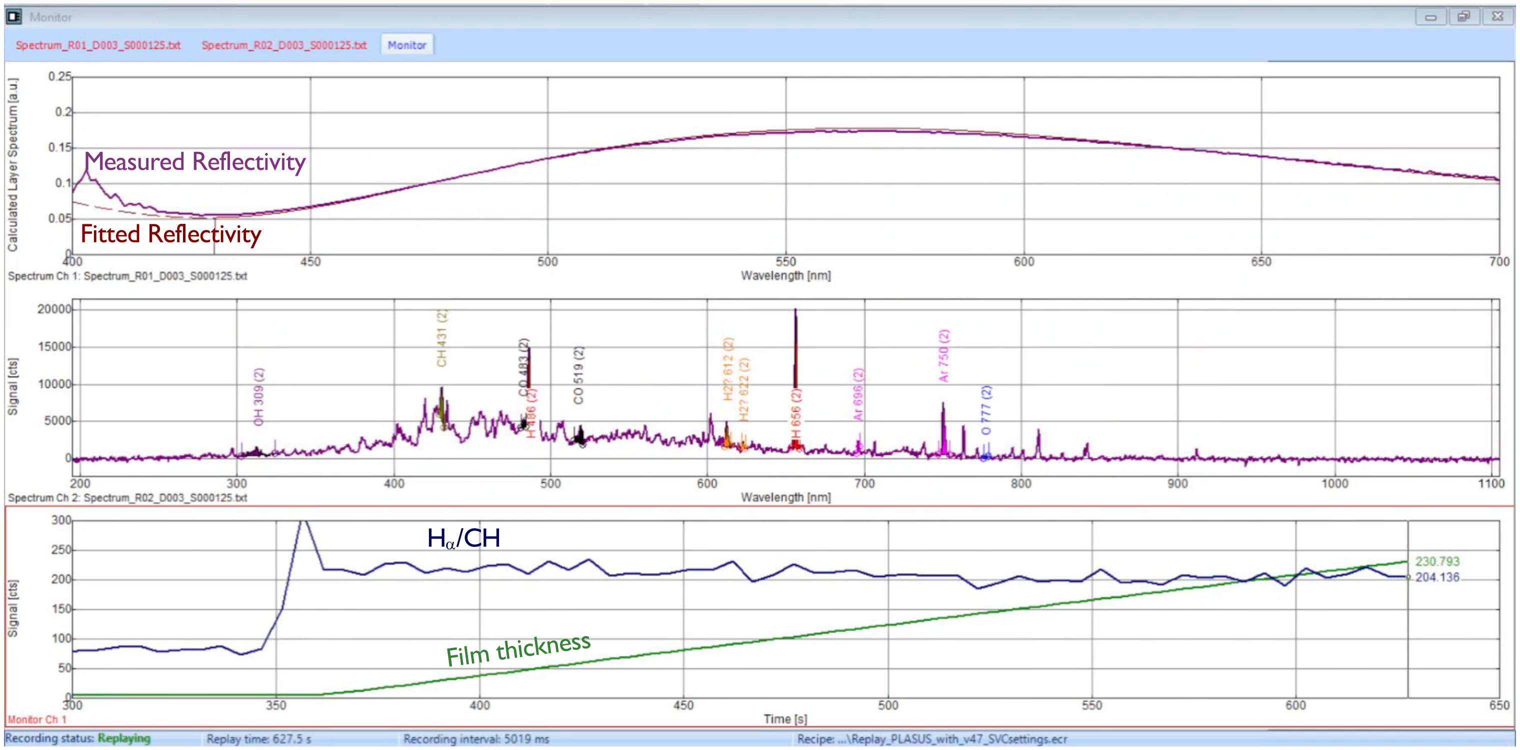
Sensor 2: Plasma emission spectrum

Spectrum Ch 2: Spectrum_R02_D011_S000107.txt

Recording status: Replaying | Replay time: 537.2 s | Recording interval: 5020 ms | Recipe: E:\...\Replay_PLASUS_with_v47_20240422.ecr*

EMICON Series with LC Module

Combined process monitoring in real-time



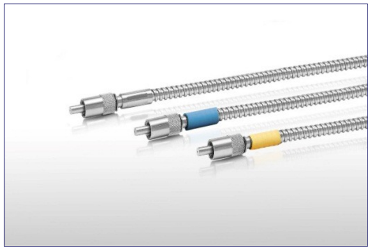
Recording status: Replaying
Replay time: 627.5 s
Recording interval: 5019 ms
Recipe: ...\Replay_PLASUS_with_v47_SVCsettings.ecr

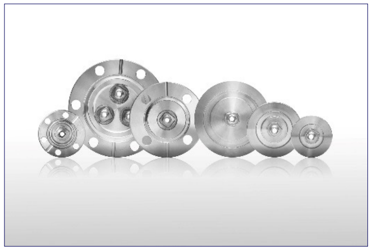
More details: PC13, Tue 05/07, 12:30 pm
Jan-Peter Urbach: Improved Process Control by Using In-Situ Data to Determine Refractive Indices of Thin Films

PLASUS Optics

for
In-Vacuum and Ex-Vacuum

Sensor heads with coating protection

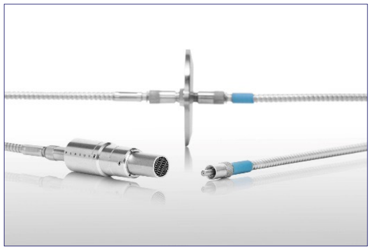


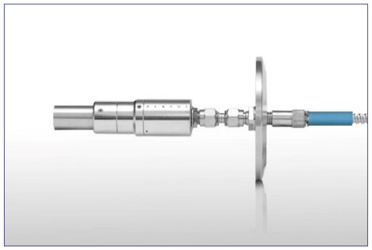


Optical fibers and feedthroughs

Assembled optics line

Coating protection for viewports





SPECLINE Software

Offline analysis software for line identification in measured data

New Version!

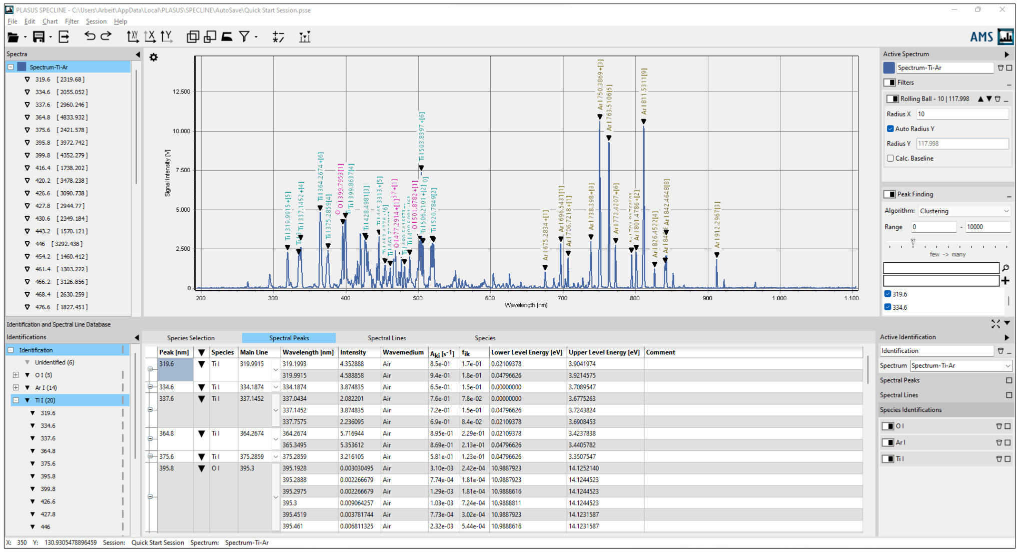
Program features:

Automatic peak finding and line identification

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

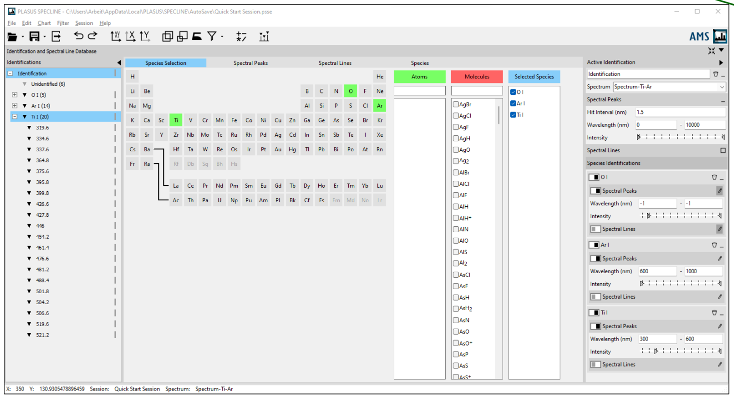
Comparing spectra form different application

Import data from all common spectroscopic data acquisition systems



Peak [nm]	▼	Species	Main Line	Wavelength [nm]	Intensity	Wavemedium	A_{ki} [s^{-1}]	f_{ik}	Lower Level Energy [eV]	Upper Level Energy [eV]	Comment
319.6	▼	Ti I	319.9915	319.1993	4.352888	Air	8.5e-01	1.7e-01	0.02109378	3.9041974	
				319.9915	4.588858	Air	9.4e-01	1.8e-01	0.04796626	3.9214575	
334.6	▼	Ti I	334.1874	334.1874	3.874835	Air	6.5e-01	1.5e-01	0.00000000	3.7089547	
337.6	▼	Ti I	337.1452	337.0434	2.082201	Air	7.6e-01	7.8e-02	0.00000000	3.6775263	
				337.1452	3.874835	Air	7.2e-01	1.5e-01	0.04796626	3.7243824	
				337.7575	2.236095	Air	6.9e-01	8.4e-02	0.02109378	3.6908453	
364.8	▼	Ti I	364.2674	364.2674	5.716944	Air	8.95e-01	2.29e-01	0.02109378	3.4237838	
				365.3495	5.353612	Air	8.69e-01	2.13e-01	0.04796626	3.4405782	
375.6	▼	Ti I	375.2859	375.2859	3.216105	Air	5.81e-01	1.23e-01	0.04796626	3.3507547	
395.8	▼	O I	395.3	395.1928	0.003030495	Air	3.10e-03	2.42e-04	10.9887923	14.1252140	
				395.2888	0.002266679	Air	7.74e-04	1.81e-04	10.9887923	14.1244523	
				395.2975	0.002266679	Air	1.29e-03	1.81e-04	10.9888616	14.1244523	
				395.3	0.009064257	Air	1.03e-03	7.24e-04	10.9888811	14.1244523	
				395.4519	0.003781744	Air	7.73e-04	3.02e-04	10.9887923	14.1231587	
				395.461	0.006811325	Air	2.32e-03	5.44e-04	10.9888616	14.1231587	

Session: Quick Start Session Spectrum: Spectrum-Ti-Ar



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**

Advanced Process Control Technology for Plasma Applications

Combining complementary in-situ diagnostic techniques in single unit

Collecting Process Data

- **Spectroscopic sensors** (line intensities, …)
- **Electrical pulse sensors** (V-I pulse curves)
- **Layer sensors** (reflection, transmission)
- **V-I sensors** (Langmuir probe, MRP, …)
- **Lambda sensor** (oxygen signal)

Evaluating and combing sensor data
&
applying control methods

Controlling process parameters

- **Reactive gas flow & ion density**
- **Process stability & system health**
- **Pulse-resolved process control**
- **Layer properties**
- **Batch-to-batch reproducibility**
- **Impurity detection**

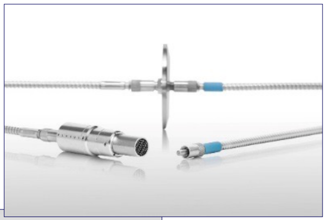
Comprehensive process monitoring and control in production lines!

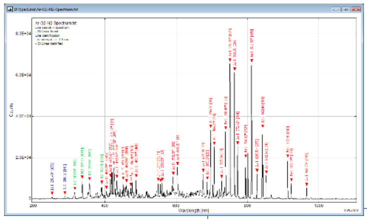
PLASUS

Spectroscopic plasma monitor and
process control systems

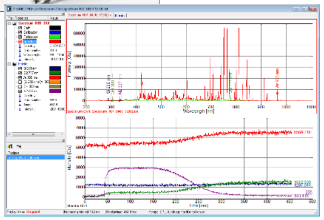
PLASUS GmbH

Meet us at booth #911





Unique
Plasma Monitoring
and
Process Control Systems



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