Optical Emission Spectroscopy Sensors
Endpoint Detection Solutions

Dry etching, cleaning or PECVD (Plasma Enhanced Chemical Vapor deposition) or atomic layer deposition/etch (ALD/ALE) process

Make your integrated circuits production faster, with constant quality by using HORIBA real-time in-situ advanced endpoint detection solutions.

Plasma is an important technology used in various process equipment such as **dry etching, sputtering, plasma CVD, and plasma surface treatment in the semiconductor manufacturing process**. These manufacturing equipment are used in a wide range of industrial fields, such as memory and logic semiconductors, compound semiconductors (LED, Laser, VCSEL), FPD / OLED or electronic components.

Plasma processes are composed of many deposition and etching steps made on various tools and chambers. All these operations can introduce variability and defects, creating lower device performance. **To ensure and guarantee excellent reproducibility, accuracy, quality, yield, and throughput, it is critical to qualify and quantify such manufacturing processes.**

- **Real time, in-situ, wafer process monitoring**
- **Accurate chamber health and fault detection monitoring**
- **Wafer uniformity control**
- **Endpoint information for**
    - Layer interfaces even for low open area structures
    - Dry chamber cleaning

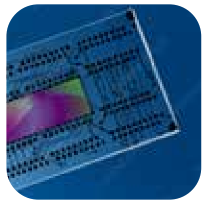
HORIBA has developed a specific line of optical sensors, based on optical emission spectroscopy (OES), dedicated to endpoint detection and plasma chamber condition monitoring.

With endpoint technology, each step is controlled in real-time to stop at the exact required point, avoiding under/over etch/deposition. With health monitoring and fault detection follow up, process steps can be operated wafer after wafer, lot after lot, respecting standard POR (Process Of Reference) within chambers.

HORIBA OES Sensors present unique benefits with:

- **Powerful algorithms and signal treatments** to allow endpoint detection even on low open area or cyclic signals. Reinforcing operational stability in the hostile environments of round-the-clock manufacturing lines.
- **Dedicated "Turnkey" solutions** including hardware and software tools to increase performance system throughput and predict if preventive maintenance is necessary.
- **Smart software** for complex processes. Based on innovative AI, unsupervised technologies and unique software architecture, including analytical methodology and sophisticated signal processing, these software solutions satisfies all the needs of in-situ plasma process control: data classification, smart wavelength selection for easy detection algorithm.


Hard disk


M.E.M.S


Microelectronics


Display


Photovoltaic


LED and compounds

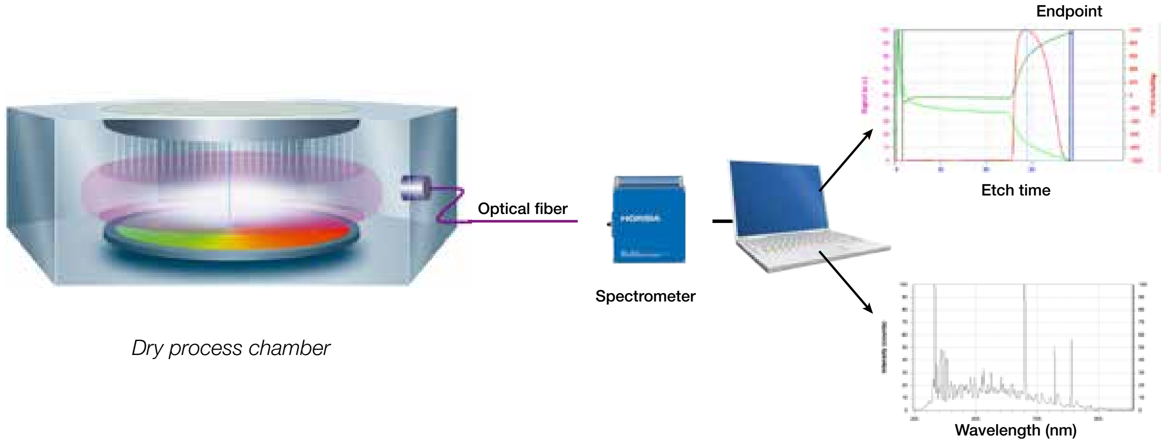
Optical Emission Spectroscopy sensor and endpoint detection

HORIBA has developed different sensors for vacuum chambers **to manage endpoint detection for dry etching process and PECVD or more complex process, such as atomic layer deposition or atomic layer etch (ALD/ALE).**

Such sensors, based on Optical Emission Spectroscopy (OES), monitor the global plasma emission during the process. OES sensors monitor relative intensity changes in the plasma emission spectrum during etching or deposition process, as elements/compounds from layers etched or deposited, react with the plasma.

By selecting appropriate wavelengths of the emission spectrum, monitoring intensity changes or stability over time, the endpoint of these etching or deposition process can be accurately determined.

The endpoint detection consists of detecting slope changes (upward or downward) in the intensity of the relevant wavelengths to stop processes at layer interfaces. With accurate endpoint detection algorithms, etch processes can be stopped precisely when required improving wafer to wafer uniformity.



Dry process chamber

Endpoint detection, chamber health monitoring, fault detection, chamber gas controls and cleaning

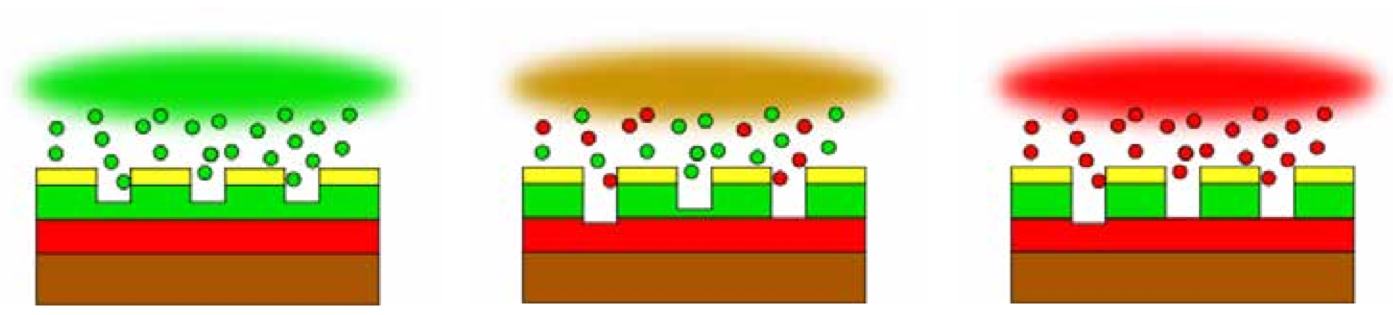
HORIBA OES sensors can be used to detect the etching endpoint at the interface of two layers or for monitoring chamber cleaning; Main applications are semiconductors, microelectronics (memory and logic circuits), optoelectronics (telecommunications, laser diodes, LEDs, VCSELs), displays, photovoltaics, hard disks, MEMS (Micro-Electro-Mechanical-Systems: micropumps, accelerometers, micromotors, gears), optical coatings, chamber cleaning, failure analysis, ….

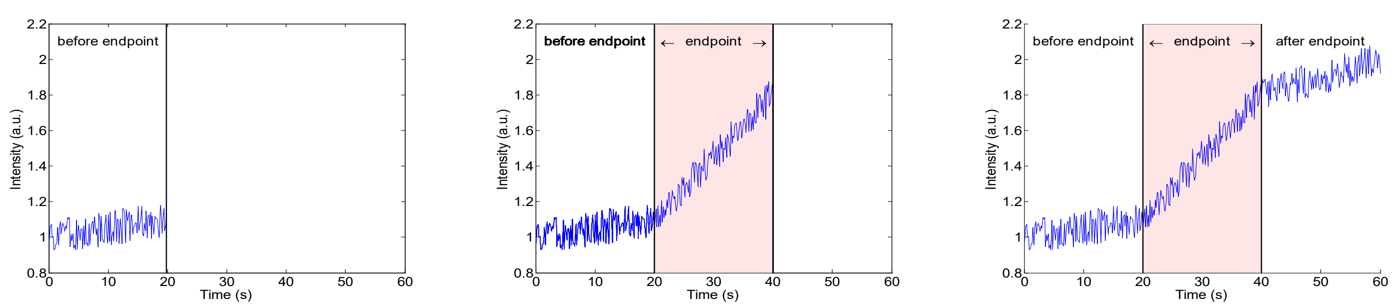
Endpoint detection

Non-exhaustive list of typical materials involved in etching steps that can be monitored for endpoint interface detection are:

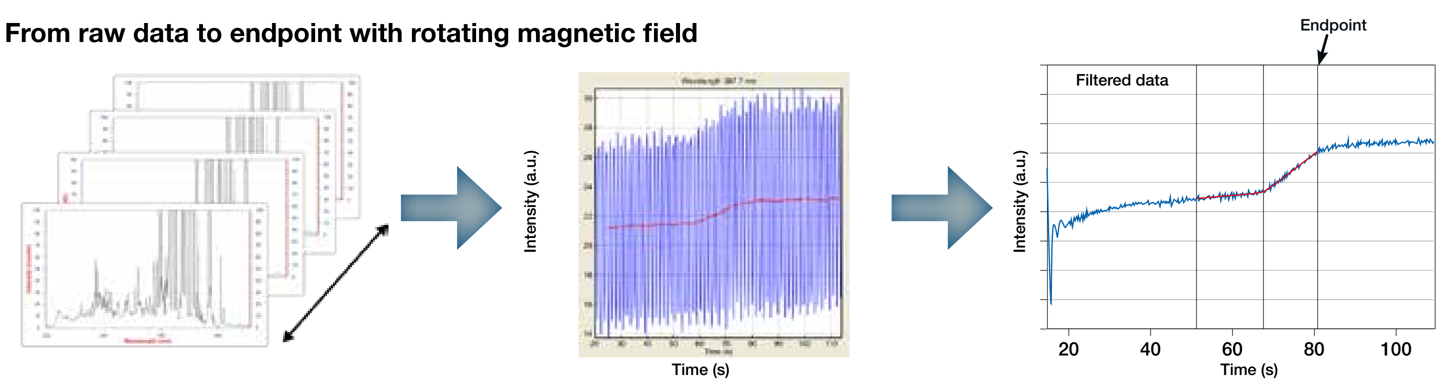
- Dielectrics (SiO_2, TiO_2, Ga_2O_3, As_2O_3, Si_3N_4, AIN, Ta_2O_5, SiON, etc.
- Si, SiC, photoresist, SOI, etc.
- Compounds III-V (InP, GaAs, AlGaAs, InGaN, AlGaN, GaN, etc.),II-VI (ZnO, CdTe, HgCdTe, etc.), IV-IV, etc.
- Metals: Ti, Cr, Al, W, etc.

Before endpoint detection **During endpoint detection** **After endpoint detection**





From raw data to endpoint with rotating magnetic field



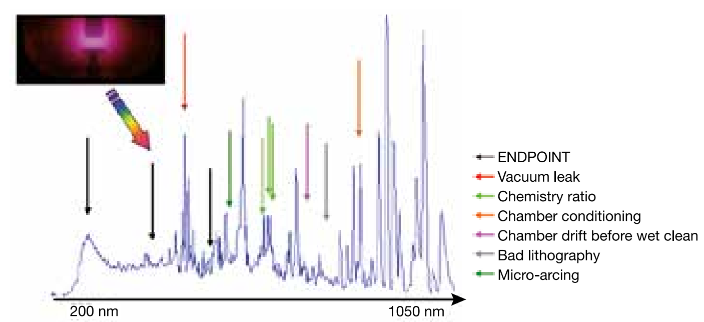
- Wavelengths selection
- Single or multi wavelengths
- Peak or area intensity…

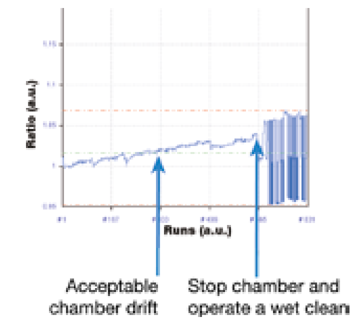
Signal processing

Endpoint detection calculation based on slope changes

Chamber health monitoring

Chamber health monitoring is the long term observation, between two wet cleans, to ensure that the chamber remains in an acceptable state for reproducible processing. This guarantees "standard chamber" conditions and alerts if conditions are abnormal (fault detection, drift) requiring preventive maintenance and thus allowing external checking/control to be reduced.

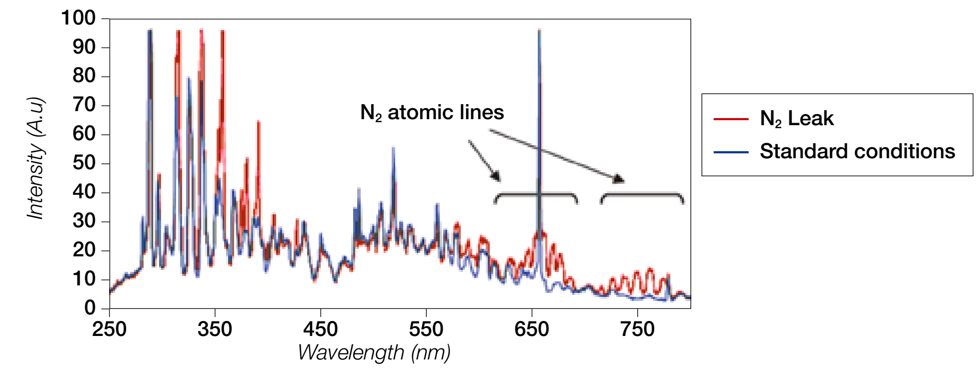




Finger printing analysis using spectral references

Fault detection of chamber gas controls

OES sensors can detect faults, leaks, arcing or abnormal gas concentrations used for plasma generation... Alerts can be set automatically to inform users about non standard conditions.



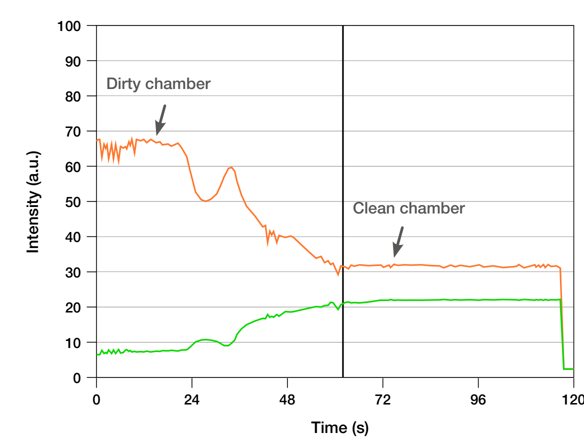
Example of N_2 leak (red spectra) versus standard conditions (Nominal blue spectra)

Cleaning

OES can also be used to follow chamber cleaning steps, material or impurities, wall deposition removal, and to keep chambers in good condition.

This helps to:

- Reduce tool to tool variability
- Optimize cleaning step duration
- Save gas and energy costs
- Improve tool throughput



Example of endpoint on cleaning

Low open area: A challenge for endpoint detection

Logic chip and contact etching: "low open area" processes, less than 2%

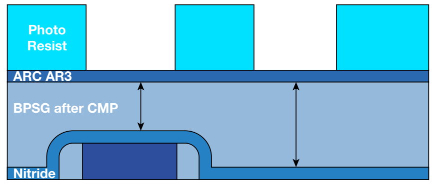
Logic circuit devices are characterized by the critical dimension of their gate electrode. This is minimized in order to increase their operating frequency. The complex wiring of logic-circuit chips, requires multiple levels of metallization, placing increased emphasis on «back-end-of-line» (BEOL) oxide and/or metal etching.

The contact dry etch process (CA process) is a critical step in the fabrication of logic devices where the main risk is obtaining an open contact.

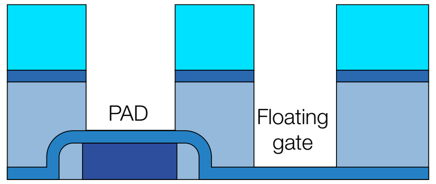
The four main challenges in contact etch process monitoring are:

- Low open area of oxide, less than 2%
- Highly selective fluorine process
- Rotating magnetic field employed in the etch tool
- Two types of contacts (pad and floating gate) have to be etched during a single step

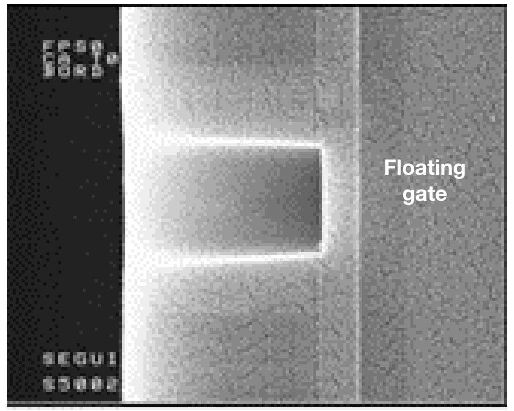
HORIBA OES sensors are designed to overcome the challenges presented by logic chip manufacturing and also to meet the plasma etching needs required for the next generation of such components.



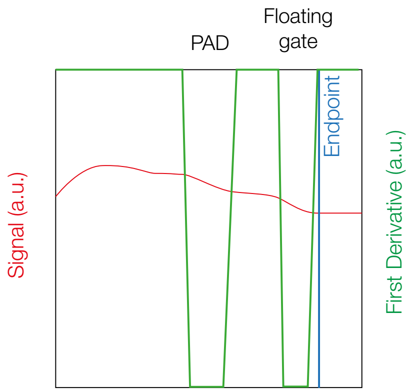
Wafer structure before CA etching



Wafer structure after CA etching



SEM cross section after the contact etch process



Example of endpoint detection display and signal treatment

Different sensors for different applications

The OES sensors family, called EV 2.0, includes several versions with different resolution and spectral range, to cover different applications. Such sensors are mounted on the chamber viewport. They can work on single chamber or on cluster tools, and offer SMA fiber or direct coupling to the chamber.

For chamber cleaning control

Model: EV 2.0 LR
Range: 300 - 900 nm
Low resolution: 6.5 nm

For Standard Endpoint

Model: EV 2.0 STD
Range: 200 - 1050 nm
Standard resolution: 2.5 nm

For specific applications requiring high resolution to separate species

Model: EV 2.0 HR
Range: 300 - 800 nm
High resolution: 1 nm

For Complex EPD: where any photon collection is key to catch process quality and Endpoint

Model: EV 2.0 HTR
Range: 190 - 900 nm
Standard resolution: 1 nm

Model	EV 2.0-LR	EV 2.0-STD	EV 2.0-HR	EV 2.0-HTR
Spectral range	300 - 900 nm	200 - 1050 nm	300 - 800 nm	200 - 900 nm
Focal length	20 mm	75 mm	75 mm	99 mm
Spectral resolution	6.5 nm or less	2.5 nm or less	down to 1 nm	1 nm
Detector	Backthinned CCD (2048 x 16 pixels)			Backthinned CCD (2048 x 192 pixels)
Dimension	70 x 135 x 125 mm	105 x 135 x 135 mm	105 x 135 x 135 mm	170 x 142 x 135 mm
Mass	610 g	850 g	850 g	2800 g
Power supply	DC 24V			
Dark noise (Integration time: 20 ms, RT)	0.05% Full scale			0.2% Full scale
Accuracy of wavelength (with 3rd order polynomial fit)	<< 0.5 nm			<< 0.02 nm
Reproducibility	<< 0.1 nm			<< 0.05 nm
Dynamic range	> 3000/1			> 5200/1
SNR Max	447			500
Minimum exposure time	1 ms for classical sensor/ 0.1 ms for fast sensor (ALE/ALD)			
Sampling time	10 ms for classical sensor/ 1.4 ms for fast sensor (ALE/ALD)			

Software platforms

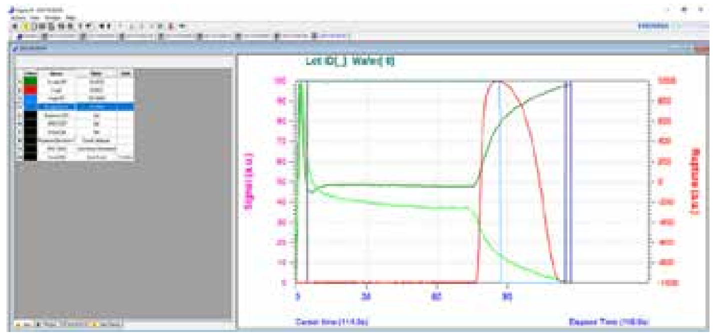
HORIBA has developed two software interfaces to follow real time processes to automatically create recipe:

- SIGMA_P, for real time acquisitions and process follow up
- RECIPE DESIGNER 2.0, for automatic generation of endpoint recipes

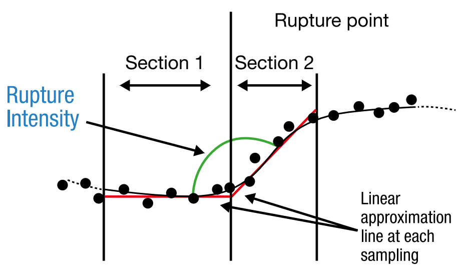
SIGMA_P: A smart software platform for “Real Time”/”in-situ” endpoint production control and monitoring

SIGMA_P is a global software platform that allows you in real time to :

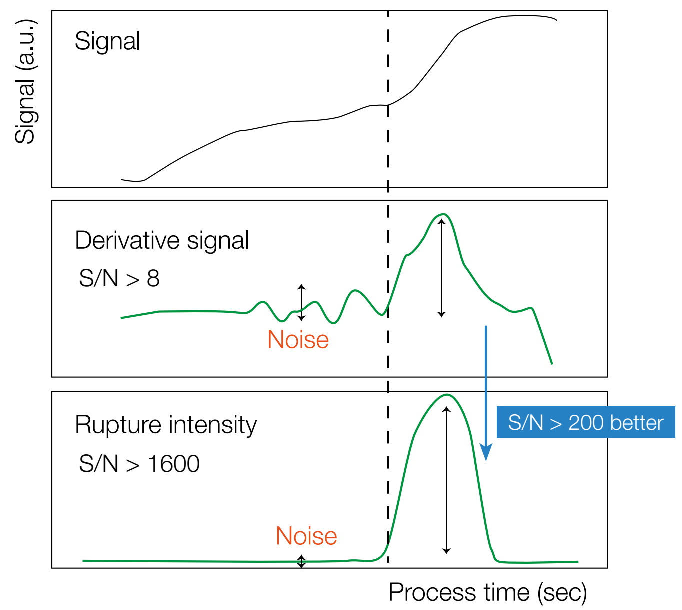
- Monitor the process
- Acquire spectra
- Load, modify and enhance endpoint recipes
- Reprocess data and check endpoint detection (EPD) validity
- Perform production controls



Sigma_P : Example of Endpoint detection display

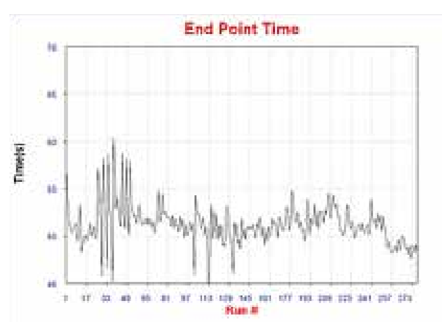


Powerful rupture algorithm calculation



Unique rupture algorithm is much more powerful than traditional signal derivatives

- Unique Rupture algorithm, more powerful than classical signal derivative
- Large panel of advanced algorithms for EPD processing
- One click concept for easy algorithm generation
- Expandable platform (single chamber or cluster tools)
- Fast recipe configuration for robust endpoint creation
- Advanced Equipment Controls (AEC) / Process Controls (APC) (wafer2wafer, Run2Run, Lot2Lot, Clean2Clean)
- SQL database for easy data comparison and interpretation
- Different users levels
- Reprocessing functions to validate a process (EPD)
- Statistical tools
- Flexible tool remote connectivity

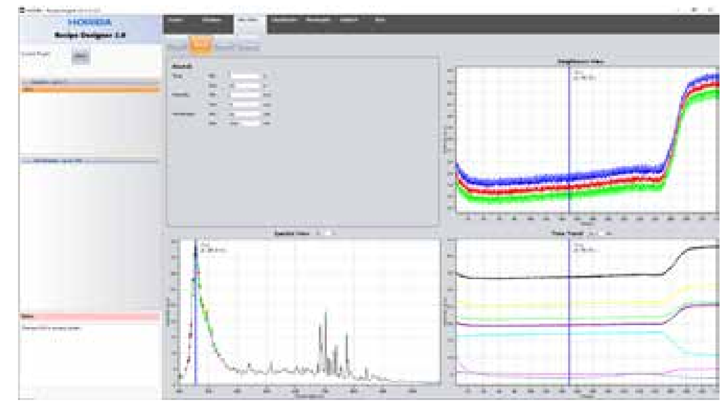


Sigma_P: Example of statistical results

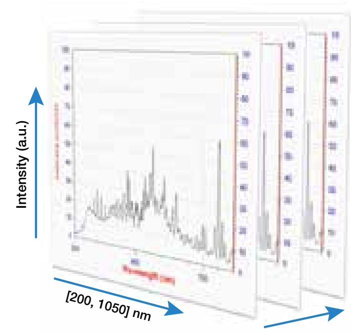
RECIPE DESIGNER 2.0 : Engineering software for automatic endpoint recipe creation

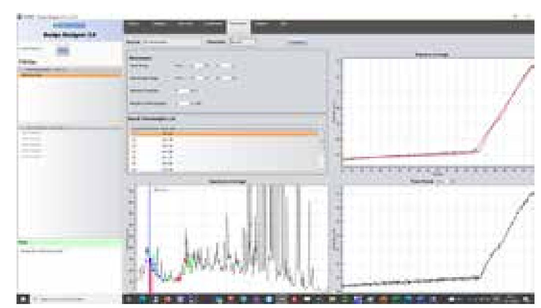
This software has been developed to allow any user, without specific skills, to build an endpoint recipe automatically.
By loading a batch of representative spectra acquired with SIGMA_P software, the software automatically identifies the best wavelengths, selecting for EPD accuracy and then creates a recipe. This recipe can be imported into the SIGMA_P software platform to first check method robustness and then to perform real process control.

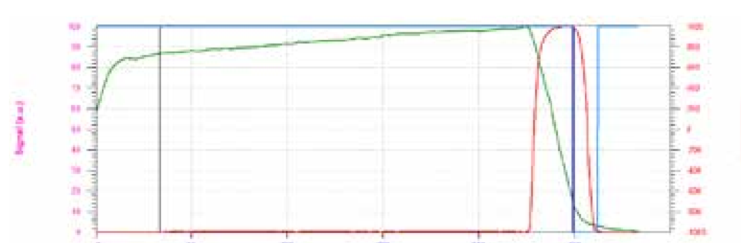
- Unique and powerful endpoint recipe creation
- Easy to use interface
- Recipe built with real acquisitions
- Automatic wavelengths selection, slope analysis and endpoint recipe creation
- Recipe robustness check on equivalent runs
- Export endpoint recipe to SIGMA_P



RECIPE DESIGNER 2.0: Example of wavelengths/species trends evolution during process







Endpoint detection flow chart

1

Run acquisitions (raw data) with SIGMA_P

2

Automatic wavelengths selection and rupture slope conditions for endpoint calculated (RECIPE DESIGNER 2.0)

3

Reprocessing EPD recipe optimization and then “real time” EPD acquisitions to check method robustness (SIGMA_P)

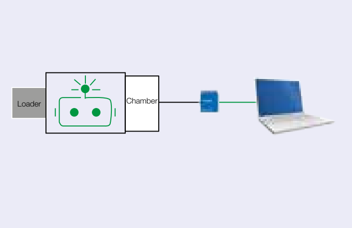
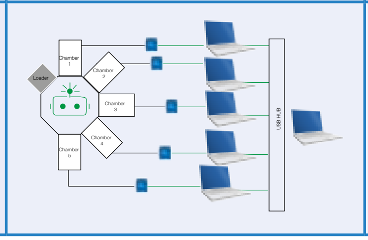
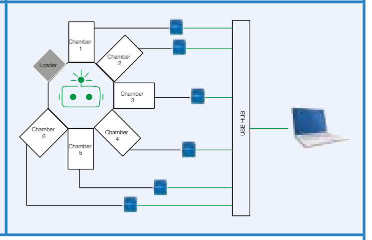
4

Start of production control: SIGMA_P

Different configurations of sensors and software tools

HORIBA OES sensors can be provided in different configurations:

1 **Complete Instrument:** Sensors with computer and full software package (Sigma_P & RECIPE Designer 2.0) for easy integration and process control.

Category	Sensor and full software		
Application	Single chamber	Cluster tool	
Model	**EV 2.0 PC-LR or PC-STD or PC-HR or PC-HTR**	**EV 2000**	**EV 2006**
Sensor Model	EV 2.0 LR or STD or HR or HTR		
Configuration	1 PC + 1 sensor	(1 PC + 1 sensor) per chamber + 1 master PC	Only 1 sensor per chamber + 1 master PC
Tools integration			
Software function			
• Spectra acquisitIon	✔ by Sigma-P		
• Endpoint recipe management	✔ by Sigma-P		
• Statistical analysis	✔ by Sigma-P		
• Spectrum analysis for automatic process engineering	✔ by Recipe Designer 2.0		
• Rupture algorithm and endpoint recipe creation	✔ by Recipe Designer 2.0		

2 Sensors only

- Sensors with Application Programmatic Interface (API), that includes several type of tools, which the user can use to develop to develop their own software for their specific application.
- Sensors with internal smart calculation based on 1 or 2 wavelengths including various signal treatments.

Category	**Sensor, Application Programatic Interface (API)**	**Sensor Smart 1.0**
Application	Single chamber	
Model	EV 2.0 API LR or STD or HR or HTR	EV 2.0 Smart 1.0-LR or STD or HR or HTR
Sensor Model	EV 2.0 LR or STD or HR or HTR	
PC	no PC	
Configuration	Sensor + Software demonstration + SDK (Software Development Kit)	Sensor* (internal calc) + basic Recipe Editor + software guidelines
Interface (independent from operating system)	Ethernet TCP/IP or customs (USB, ttl uart)	
Messaging	JSON	
Software Development kit provided	- Documentation - Source code samples - Demonstration software JYST PC Win* - API Spectrometer firmware upgrade file	- Documentation - Source code samples - Demonstration software JYST PC Win* - SMART 1.0 Spectrometer firmware upgrade file - Recipe Editor to manage Time trend recipes
Functions	Basic functions available and Managed by integrators for its own application: **Main functions on SDK:** - Spectra acquisition (single, continuous, timed periodic, trigger) - ROI Modes (pixel range, wavelength range, image) - Various signal treatment - Analog output - General purpose I/O - configuration (calibration)	Internal SMART functions immediately available in recipes **Main functions on RECIPE:** - Wavelength(s) acquisition (timed periodic) - ROI Modes (pixel range, wavelength range) - Various signal treatment - Analog output - General purpose I/O - Sensor basic calculation (formula, filtering) - Recipe management: Modify/edit/save/download - Remote control process automation: Set recipe/Start/Stop

* JYST: basic software application to monitor spectra (csv format)

3 Fast "sampling" sensors for ALE / ALD

For specific applications with fast cycles, such as ALE or ALD, sensors with faster exposure time (down to 0.1 ms) and sampling (down to 1.4 ms) can be supplied.

HORIBA global portfolio for semiconductor applications

Endpoint process sensors

HORIBA has developed a full product line of sensors dedicated to real-time in-situ advanced endpoint process control, fault detection and chamber health monitoring for semiconductor industries.

Complementary to these OES sensors, based on plasma monitoring, another series of sensors, based on laser or multi wavelength interferometry, monitor wafer changes during processes.

These allow:

- Endpoint on thickness
- Etch and deposition rate and thickness measurement
- Endpoint by fringe counting
- Stop on remaining thickness

LEM Camera

EV 2.0 Spectrometer

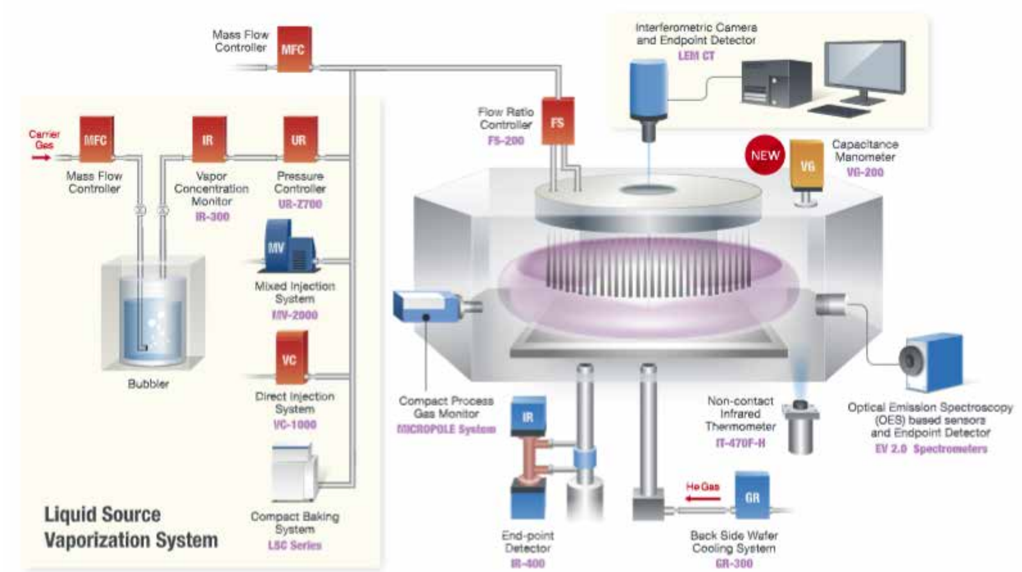
All these sensor solutions can be used in a large range of processes such as Dry Etching, cleaning and (Plasma Enhanced) Chemical Vapor Deposition or Atomic Layer Deposition / Atomic Layer Etching.

Research and Academic sensors

For applications, requiring wider spectral range or higher resolution, HORIBA can customize solutions based on specific customer requirements.

Dry process complete solutions

HORIBA has a full product line of dry process sensors and also metrology equipment based on various principles to support semiconductor process control characterization needs.



HORIBA France S.A.S.

Passage Jobin Yvon, 14 boulevard Thomas Gobert
CS 45002, 91120 Palaiseau,
France

Tél : +33(0)1 69 74 72 00

info-semi.fr@horiba.com

www.horiba.com