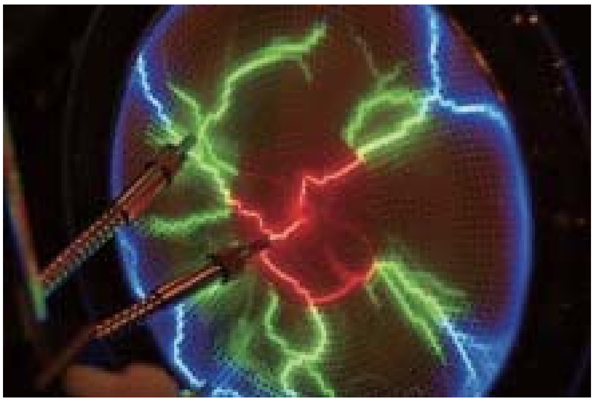
Plasma Measurement
高性能プラズマ計測システム

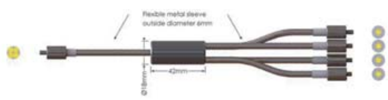
Avantes社の高性能･万能型ファイバー入射型分光器は新開発の迷光が極端に少ない光学ベンチ(AvaBench-ULS)を採用し、用途に応じたスリット･グレーティングを選択することにより、高速で非常に高い波長分解能を実現しています。



プラズマのより高性能な計測の為に開発された高性能プラズマ計測システムは、Avantes社のベストセラー製品である高性能･万能型分光器を複数チャンネル使用した、マルチチャンネル分光器システムです。
専用に開発された分析用ソフトウエアと独自の光ファイバー、オプション等と使用することによりプラズマの幾つもの放射ピークを紫外域～近赤外域まで的確に捉えることが可能で、これまでに無い、高波長分解能での計測が実現します。

◆低コスト、 高波長分解能プラズマ計測システム

波長域 200 ～ 1030nm の高性能 4ch 分光器を使用したシステムで 0.18 ～ 0.22 の高波長分解能での計測を実現しました。
独自開発の AvaSoft 分光器ソフトウェアにより、あたかも1台の分光器で計測しているが如く、4ch がスムーズに動作・計測でき、 デスクトップ上で操作できます。 一体型なので無駄が無く、 コスト的にも費用効果が高い、 高波長分解能小型プラズマ計測システムです。

ファイバー入射型分光器	4ch デスクトップ型 AvaSpec-ULS2048-USB2 ４台内蔵	グレーティング　スリット　波長分解能 ・UC (200-458nm)　10μm　0.18nm ・VC (455-683nm)　10μm　0.19nm ・NC (680-974nm)　10μm　0.20nm ・NC (870-1030nm)　10μm　0.22nm オプション ・DCL-UV/VIS detector collection Lens ・OSF-600 order sorting filter (必要な波長に)
ソフトウェア	AvaSoft-Full SPECline-A	AvaSpec 用万能ソフトで ch 毎の計測・データ集積・処理・変換・表示などの機能の基本ソフト 分析・解析用ソフト
ファイバー	FC4-UVIR400-2	多分岐ファイバー4x400μm fiber 

◆超高波長分解能プラズマ計測システム

さらに高感度・高波長分解能でプラズマ計測する為のシステムで、 波長域 200 ～ 1070nm の高性能 8ch 分光器を使用して 0.10nm の高波長分解能での計測を実現しました。
独自開発の AvaSoft 分光器ソフトウェアにより、あたかも1台の分光器で計測しているが如く、8ch がスムーズに動作・計測でき、 紫外域から近赤外域までカバーできます。 最大 10chまで拡張でき、 ラックマウントに収納した使い易い形です。 一体型なので無駄が無い高波長分解能小型プラズマ計測システムです。

ファイバー入射型 分光器	8ch ラックマウント型 AvaSpec-ULS2048-USB2 8 台内蔵	グレーティング　スリット　波長分解能 ・UE (200-320nm)　10 μ m　0.10nm (318-420nm)　10 μ m　0.10nm (417-505nm)　10 μ m　0.10nm ・VE (500-565nm)　10 μ m　0.10nm ・VD (565-670nm)　10 μ m　0.12nm ・VD (688-750nm)　10 μ m　0.14nm ・NC (745-930nm)　10 μ m　0.20nm ・NC (920-1070nm)　10 μ m　0.22nm オプション ・DCL-UV/VIS detector collection Lens ・OSF-600 order sorting filter (必要な波長に)
ソフトウェア	AvaSoft-Full SPECline-A	AvaSpec 用万能ソフトで ch 毎の計測・データ集積・処理・変換・表示などの機能の基本ソフト 分析・解析用ソフト
ファイバー	FC8-UVIR400-2	多分岐ファイバー 8x400 μ m fiber

用途： 半導体　太陽電池　核融合炉　剃刀の刃　ガラスコーティング

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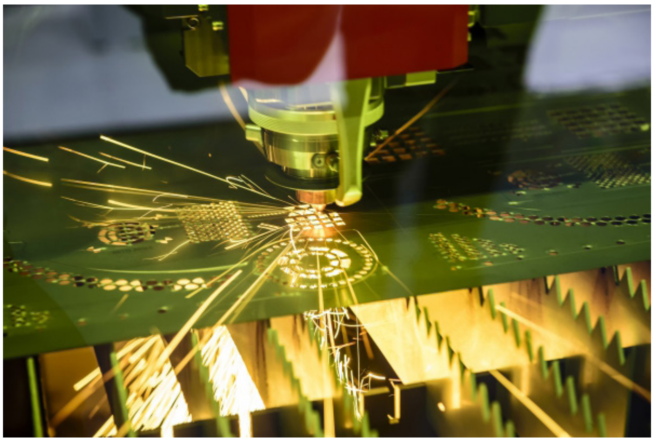
Spectroscopy Applications for Plasma Monitoring

Exploring the use of optical emission spectroscopy (OES) as a form of plasma monitoring during the manufacturing of electronics



Plasma etching (Shutterstock)

Plasma is an ionized gas under pressure and subjected to intense heating or electromagnetic fields to the point that electrons and positive ions are unbound. Plasma is one of the four fundamental states of matter, but it does not exist on Earth naturally and must be generated by applying heat and pressure. What makes plasma unique from other states of matter is its behavior. The speed of atoms in a plasma are higher than in a gas. This movement of charged particles creates an electric current within a magnetic field, and while the overall charge of a plasma is usually neutral, it is also highly conductive.

Even though plasmas are rare at normal Earth conditions, plasma is considered to be the predominant state of matter throughout the universe. For instance, the sun and stars are examples of fully ionized plasma, while neon lighting is only partially ionized.
Plasmas are used for a large number of applications in spectroscopy. Most commonly might be thin film deposition and photo-resist etching for semiconductors and solar collectors, but plasmas also have applications in biomedical and aerospace, along with other industries. Plasma diagnostics demand high-resolution spectra and high-speed data capture that Avantes is known for. Our instruments can be found in plasma research and industrial environments all over the globe.

Applications

When a matter turns into plasma, it can be monitored using optical emission spectroscopy (OES). As each atom's emission spectrum is unique, it is possible to measure the spectra and identify the atoms present in the plasma. Plasma monitoring is used in a variety of industries to identify and detect the additions in and during a plasma process, or to control the process or sequence in general.
In the semiconductor industry, plasma monitoring is used to measure the process during etching of a photo resist, a light-sensitive material which is used to form a patterned coating on a surface. Plasma monitoring facilitates the process through, for example, end point detection.
Optical emission spectroscopy (OES) can be used to monitor the contamination of the repositioning of hydrocarbons from chamber wall elements. OES may also be used in the monitoring of co-deposition of deuterium and tritium. OES is often used in the biochemical industry to monitor surface modifications using plasma etching to improve biocompatibility of materials.
Thin layers of carbon impurities are found on optical components in both fusion reactors and lithography devices, thereby reducing the reflectivity of the mirrors. Plasma etching has been proposed as a method to remove these impurities, without damaging the optics. Optical emission spectroscopy is a suitable tool for in situ monitoring of the etch process.

Optical emission spectroscopy in the fabriction of integrated circuits

Plasma processing is one of the most widely used techniques in modern electronics manufacturing, particularly when it comes to the fabrication of integrated circuits (ICs) and other types of microelectronics. Many large-scale ICs can contain as many as 400 different individual layers, and to build such complex structures each layer typically requires both an epitaxial growth and a plasma etching step. For proper functionality of the IC, it is critical during the etching process that the material from the newly applied layer being etched is removed completely without damaging the subsequent layer below. To make the process even more difficult, plasma etching must be performed under vacuum to prevent deposits of unwanted contaminants. Luckily, during the ionization process, vast amounts of energy are transferred to the ionized material, which results in the release of massive amounts of light.

Exploiting changes in energy state

This emission of photons results from the atoms being first excited to a higher electronic state, and then spontaneously dropping back down to the ground state. During the process, since the total energy is conserved, the emitted photons must have an energy equal to the difference between the excitation state and the ground state. The amount of energy transferred in this process is a unique property of the particular species of atom undergoing the transition. Since the frequency of the light, and therefore its wavelength, are directly proportional to the energy of the photon, by collecting the

emitted light and measuring its spectrum, it is possible to determine which elements are present.
This technique, known as optical emission spectroscopy (OES), gives process engineers the ability to monitor the plasma etching process and detect the endpoint when a layer is completely removed. By providing this real-time monitoring capability, IC manufacturers can fully automate the etching process, without fear that they will over or under etch the layer. Figure 1, courtesy of Professor Richard van de Sanden's Plasma and Materials Process (PMP) group at the Eindhoven University of Technology, shows an example of this process where the 431nm CH line was monitored during the etching process by collecting the emission and coupling it into one of our spectrometers via a fiber-optic cable. Additionally, OES has the intrinsic benefit of automatically notifying the user when they have reached the previous growth layer by the appearance of spectral lines corresponding to the layer below.

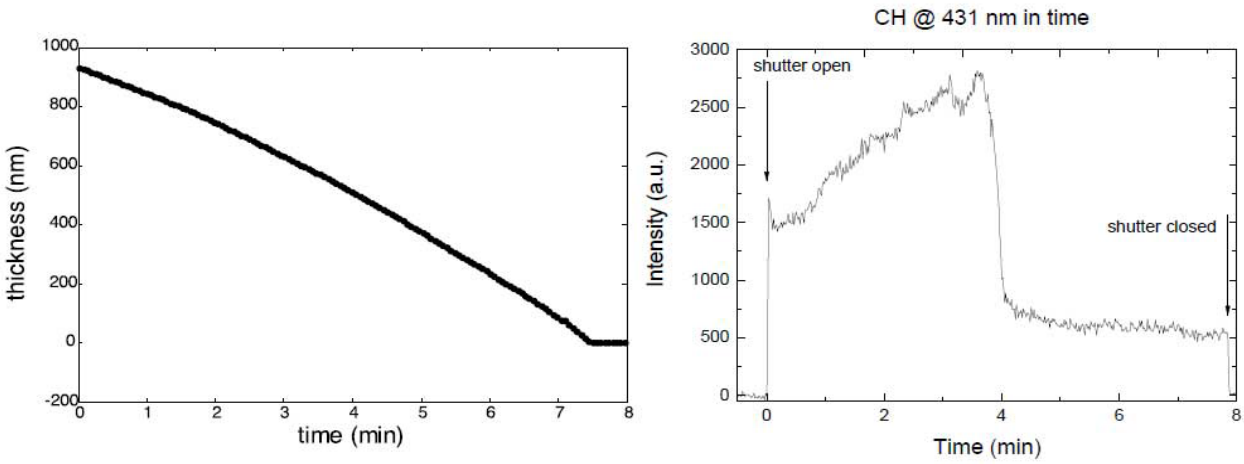


Figure 1. Etching depth and 431 nm spectral peak intensity for monitoring CH content (Eindhoven University of Technology

Working in vacuum environments

When possible, it is preferable to monitor the process through an observation window in the vacuum chamber utilizing a collection lens (sometimes referred to as a collimating lens) placed near the window to couple the light into a fiber optic cable. Unfortunately for many large scale industrial epitaxial growth reactors and plasma etchers, it is not always possible to do so, in these cases, it is necessary to utilize vacuum seal fiber optic feedthroughs to bring the fiber closer to the wafer. While more complex, vacuum feedthrough fiber-optic assemblies are mature technologies that are commercially available.

Resolution is key

As with most atomic spectroscopy techniques, OES generally requires very fine spectral resolution to differentiate between similar atomic species. For this reason, compact spectrometers are an ideal choice for this application. For example, the AvaSpec-ULS4096-EVO, as shown in Figure 2, can provide 0.05 nm resolution within the range from 200-400 nm using a 3600-grove density grating. Additionally, this spectrometer has a CMOS detector array which is ideal for high light level applications such as this one because of its superior linearity and dynamic range when compared to more commonly used CCD detectors. When combined with proprietary high-speed electronic triggering, data transfer rates, and analog and digital I/O capabilities the AvaSpec series provides seamless integration into high-speed wafer etching systems.

Figure 2. AvaSpec-ULS4096CL-EVO (Avantes)

Spectral range v. resolution

While some OES systems may be designed as "fit-for-purpose" instruments which only require a limited spectral range to identify a select number of atomic species, the vast majority of OES applications involve the identification of a wide range of elements. As a result, these systems need rather large spectral ranges, leading to a fundamental limitation of fixed grating spectrometers, the inverse relationship between spectral range and resolution.

Avantes' instruments for OES benefit from an optical design which offers a superior response, allowing for 0.5 nm resolution over the full range from 200-1100 nm. Additionally, these spectrometers are designed to be multiplexed, or concatenated together, enabling multichannel operation. This allows each spectrometer in the system to be optimized for spectral resolution over a small range, typically of 200 nm – 300 nm. In these multiplexed systems, the collected OES signal can be split evenly amongst the instruments using a multichannel fiber optic bundle. This provides a more stable, faster, and less expensive alternative to large scanning spectrometer alternatives. Depending on the integrator's preference, these multichannel spectrometer systems are available as both individual OEM board components, or custom turn-key rackmount systems as shown in Figure 3.

More applications for OES

While endpoint detection of semiconductor plasma etching is the most popular application of OES used to date, there are many scientific and research applications for this technology as well. A full analysis of each of these options is beyond the scope of this application note, but it is worth briefly mentioning a few of them here.

Figure 3. AvaSpec multi-channel fiber-optic spectrometers (Avantes)

OES has been widely deployed in metal foundries for monitoring steel, copper, and aluminum purity by measuring the emission from these metals in the mutant form. OES can also be used in quality control laboratories as a low-cost alternative to mass spectrometry (MS), especially when combined with inductively coupled plasma (ICP). IPC-OES is commonly used in the automotive, aviation, and recycling industries for rapid analysis to verify elemental content where ICP-MS would be overkill. OES is also used effectively in the monitoring of laser ablation spectrum during metallic additive manufacturing processes.

Why choose Avantes for your plasma application?

- Avantes supports synchronous measurement across multiple spectrometer channels to acquire the spectrum of a plasma at the same moment every time. AvaSoft software stitches these spectra together.
- Avantes offers high-resolution measurements (0.1 nm FWHM or higher) to resolve and identify atomic lines and molecular spectra within plasma.
- Avantes provides the option to acquire spectra at high speeds (ms time scale) and communicate events via digital and analog ports.

Plasmas are known for their many emission peaks, located closely together. To separate these peaks, Avantes has developed multi-channel spectrometers, featuring much higher resolution than any stand-alone device. Avantes has made two multi-channel spectroscopy bundles especially developed for plasma monitoring. To find out about the possibilities of these bundles, please visit our website or contact us directly.

About Avantes

Avantes is the leading innovator in the development of fiber-optic spectroscopy instruments and systems with 25 years of experience developing customer-defined configurations. With a long history of consulting with clients across diverse industries and applications, Avantes is an experienced partner, equipped to guide customers who want a solution tailored to their application and research needs. Avantes offers customers the peace of mind that the solutions they purchase will meet, and exceed, their expectations.

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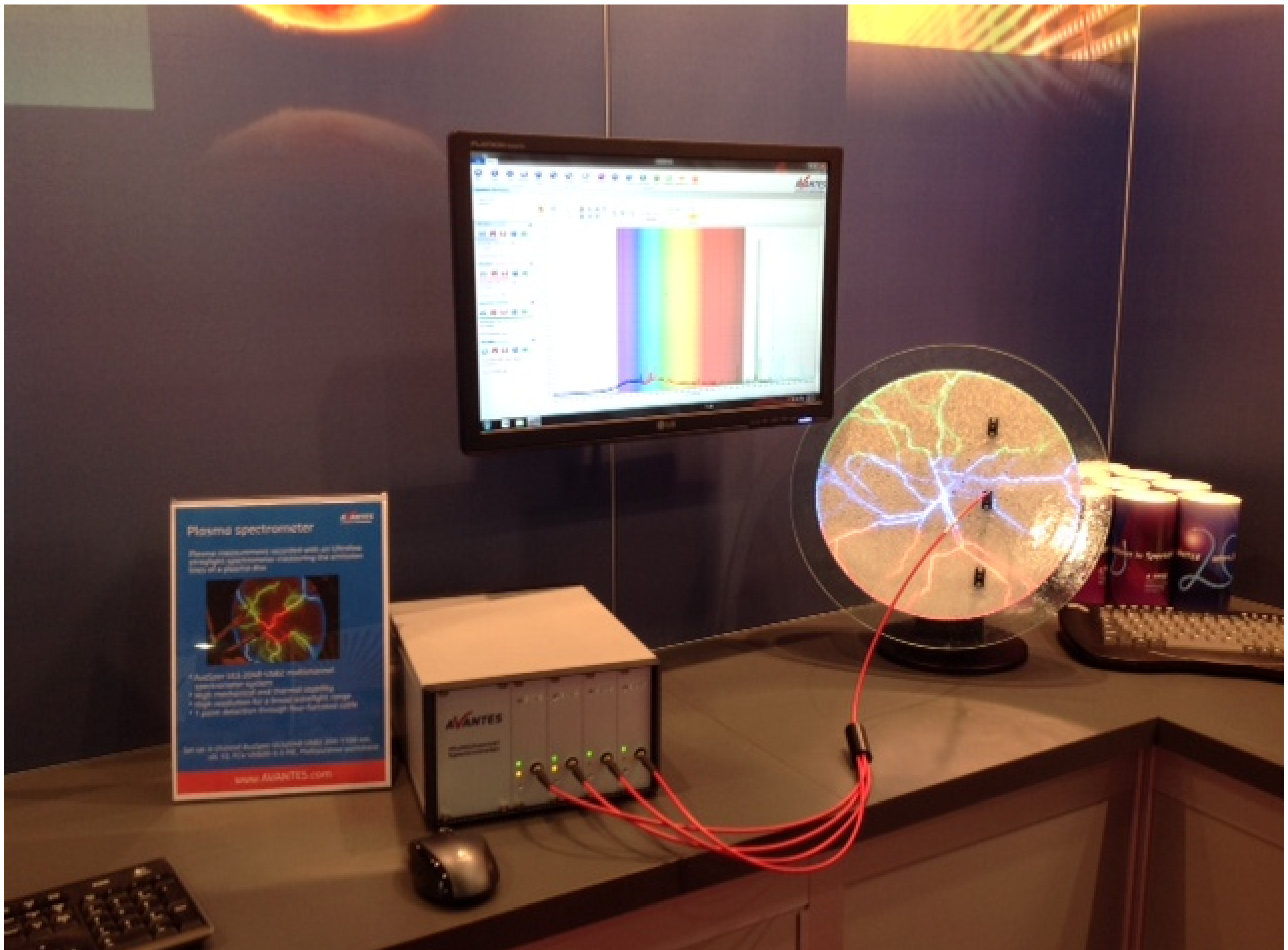
Introduction of Avantes Plasma application



MultiChannel
High Resolution spectrometer

Avantes has some great advantages in LIBS applications:

- Multirack in combination with resolution
- Timing and triggering
- Extensive knowledge on LIBS

8CH (resolution 0.1nm) , 4CH (resolution 0.2nm)

Application LIBS configurations

Spectrometers AvaSpec-ULS2048/4096CL-EVO (Starline) - CMOS—2048/4096 pixels
AvaSpec-ULS2048XL-EVO(Sensline) - back thinned CCD—2048 pixels

Gratings Range & Resolution
Grating UE (2400 lines/mm) , DUV, 190-309 nm, 0.09 nm (FWHM)
Grating UE (2400 lines/mm), DUV, 307-410 nm, 0.07 nm (FWHM)
Grating VE (2400 lines/mm), OSF-385, 408-494 nm, 0.06 nm (FWHM)
Grating VD (1800 lines/mm), OSF-475, 493-616 nm, 0.09 nm (FWHM)
Grating VD (1800 lines/mm), OSF-550, 615-715 nm, 0.07 nm (FWHM)
Grating VC (1200 lines/mm), OSF-600, 714-902 nm, 0.14 nm (FWHM)

Fiber Optics Multi-furcated fibers optic splitters—see Avantes catalog
Accessories IC-DB26-EXTRIG-BNC-2—external triggering cable

Measurement cycle CMOS (S11639-01)

- CMOS timing:
    - Minimum integration time 30 µs
    - No parallel signal collection (integration) and read-out
    - Clock frequency 6 Mhz → with 2048 pixels → read-out time ≈350 µs.
    - Data transfer time USB3: < 380 µs (350 +30 µs)
    - Data transfer time USB2: ≈ 650 µs
    - Data transfer time Ethernet = 1000µs

AvaSpec-ULS2048CL

Integration time	9 µs – 59s
Interface	USB 3.0 high-speed, 5 Gbps Gigabit Ethernet 1 Gbps
Sample speed with on-board averaging	0.38 ms /scan
Data transfer speed	0.38 ms/scan (USB3), 1.0 ms (ETH)

CMOS detector have very fast timing about minimum integration time is 9us.
Data processing of USB 3 in 2048CL is about 350us.

Grating Selection Table for AvaSpec-ULS2048CL-EVO

Use	Useable range (nm)	Spectral range (nm)	Lines/mm	Blaze (nm)	Order code
UV/VIS/NIR	200-1100**	891**	300	300	UA
UV/VIS/NIR	200-1100**	891**	300	300/1000	UNA-DB
UV/VIS	200-850	515	600	300	UB
UV	200-750	247-218*	1200	250	UC
UV	200-650	163-143*	1800	UV	UD
UV	200-580	113-69*	2400	UV	UE
UV	200-400	69-45*	3600	UV	UF
UV/VIS	250-850	515	600	400	BB
VIS/NIR	300-1100**	792**	300	500	VA
VIS	360-1000	495	600	500	VB
VIS	300-800	247-218*	1200	500	VC
VIS	350-750	142-89*	1800	500	VD
VIS	350-640	74-49*	2400	VIS	VE
NIR	500-1050	495	600	750	NB
NIR	500-1050	218-148*	1200	750	NC
NIR	600-1100	346-297	830	800	SI
NIR	600-1100**	495**	300	1000	IA
NIR	600-1100	495	600	1000	IB

* depends on the starting wavelength of the grating; the higher the wavelength, the bigger the dispersion and the smaller the range to select.

** please note that not all 2048 pixels will be used for the useable range

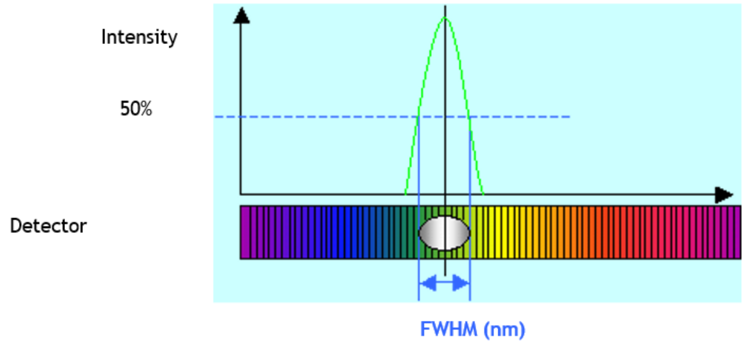
Avantes spectrometer have lots of kind gratings. U is UV range. V is visual range. I is Infrared range.
A is 300 /mm, B is 600 /mm, C is 1200/mm, D is 1800 /mm, E is 2400 /mm, F is 3600 /mm

Resolution Table (FWHM in nm) for AvaSpec-ULS2048CL-EVO

Grating (lines/mm)	Slit size (µm)					
	10	25	50	100	200	500
300	1.0	1.4	2.5	4.8	9.2	21.3
600	0.40-0.53*	0.7	1.2	2.4	4.6	10.8
830	0.32	0.48	0.93	1.7	3.4	8.5
1200	0.20-0.28*	0.27-0.38*	0.52-0.66*	1.1	2.3	5.4
1800	0.10-0.18*	0.20-0.29*	0.34-0.42*	0.8	1.6	3.6
2400	0.09-0.13*	0.13-0.17*	0.26-0.34*	0.44-0.64*	1.1	2.7
3600	0.06-0.08*	0.10	0.19	0.4	0.8	1.8

* depends on the starting wavelength of the grating; the higher the wavelength, the bigger the dispersion and the better the resolution

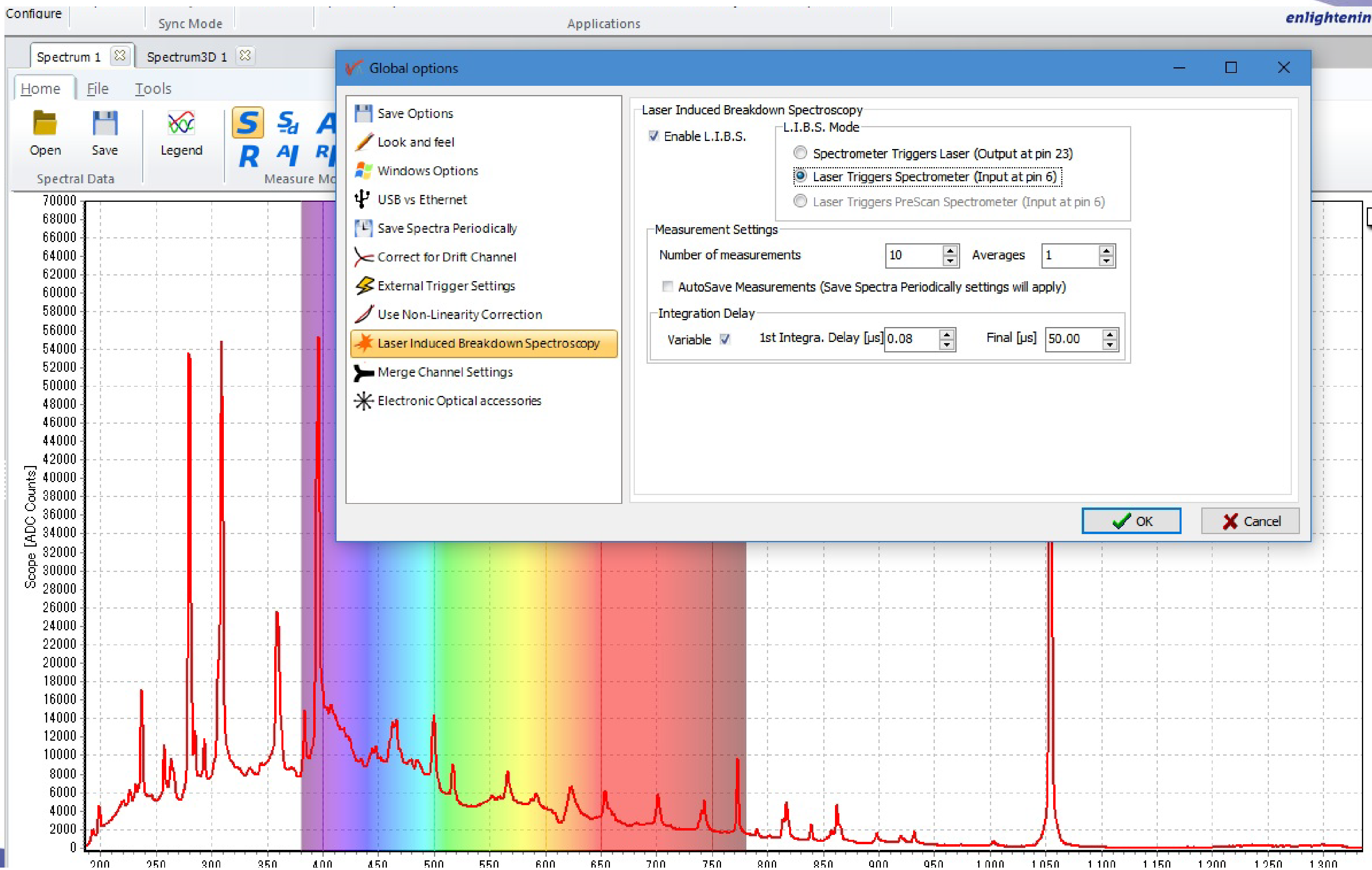
Optical Resolution



Non-weighted smoothing in software
Pixel dispersion = range / # pixels (0.25nm for 600 lines)

The unit of resolution is nano meter in FWHM (Full Width Half Maximum).
The resolution is determined by slit size (um) and grating lines.
For example at the grating line 3600 and slit size 10um, the resolution is 0.06-0.08nm.

Trigger In（外部トリガーケーブル機能



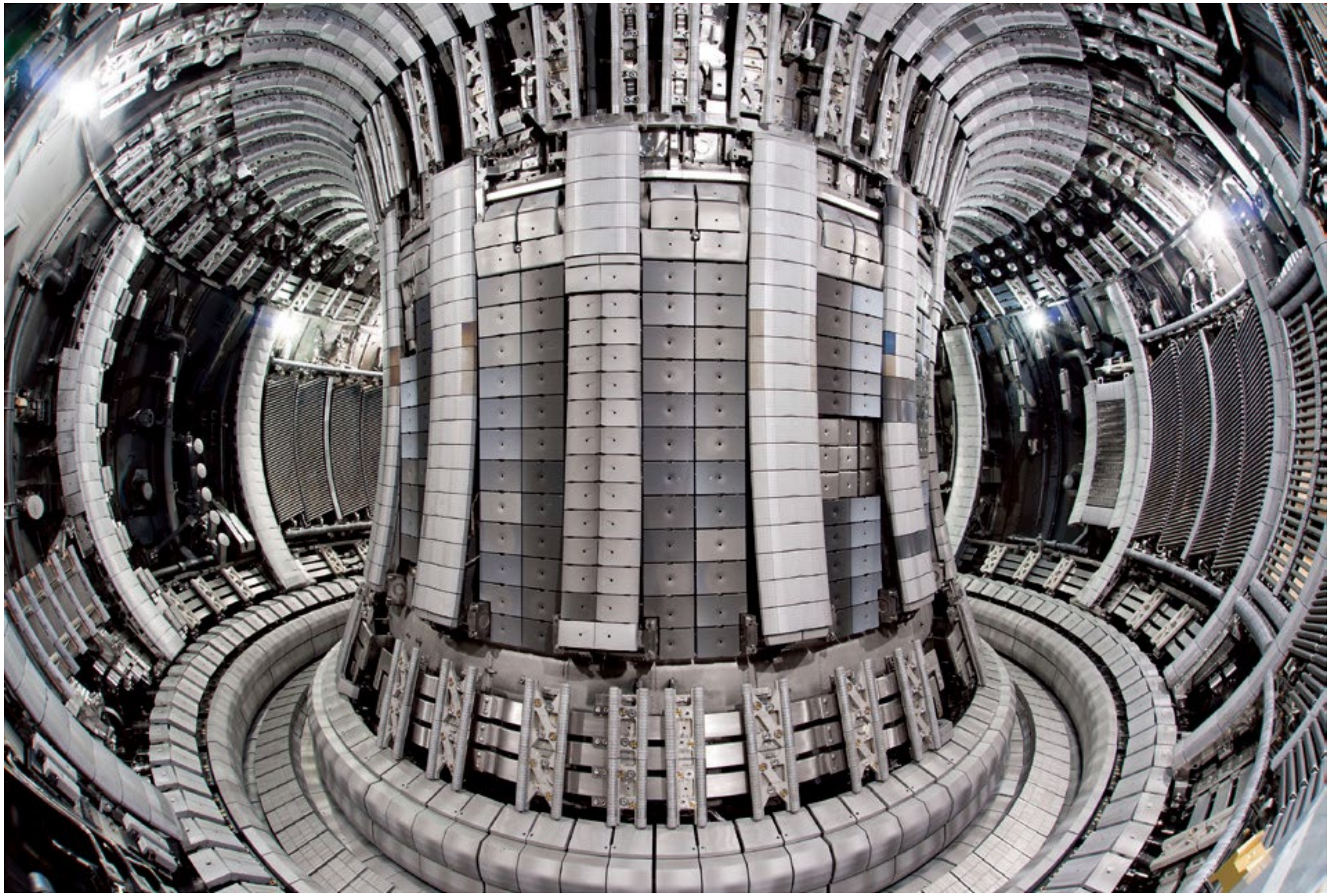
Trigger in is laser control (trigger) spectrometer.

AVANTES
solutions in spectroscopy

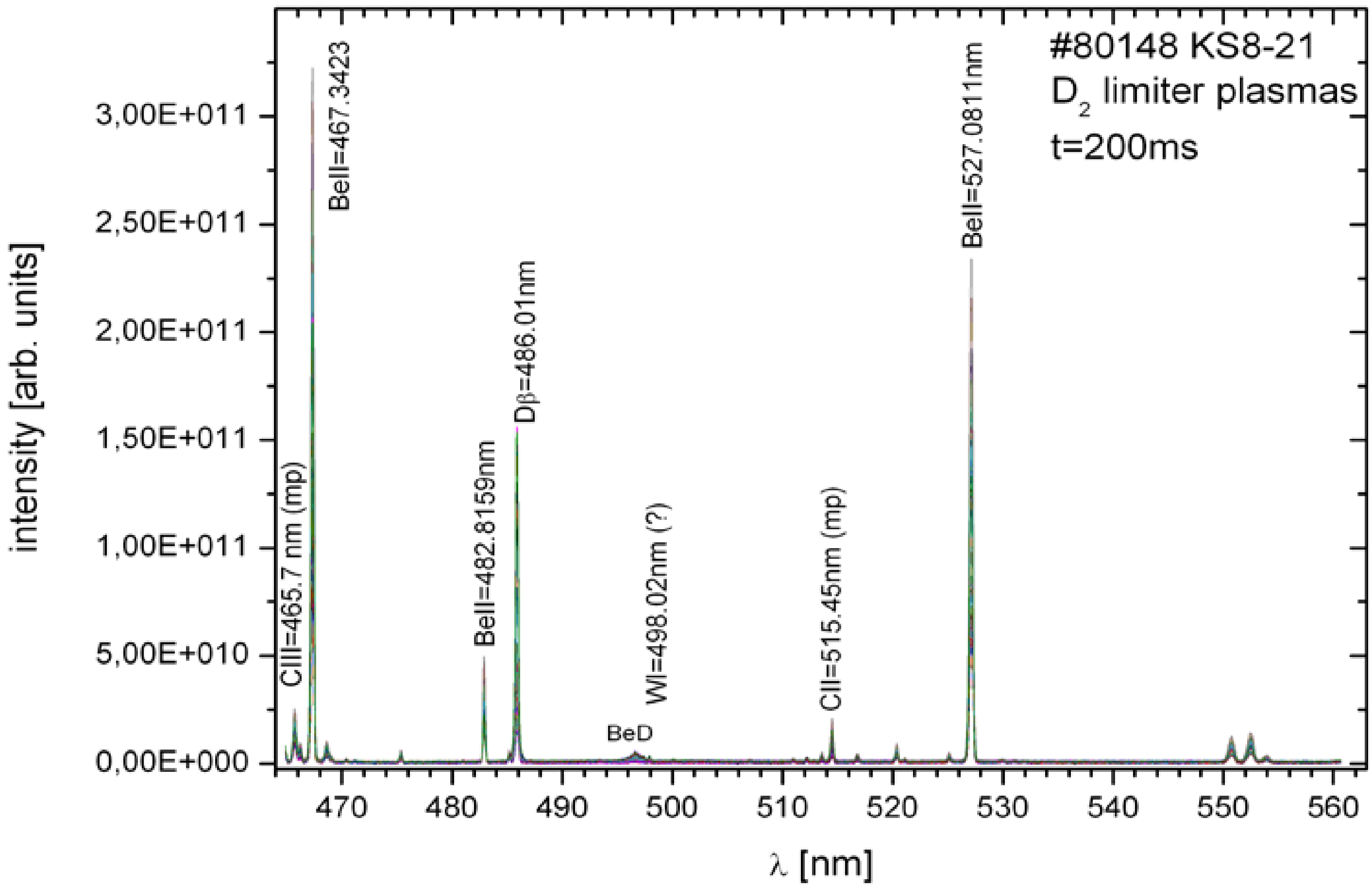
Avantesプラズマ測定例

EFDA JET

Wall Flux Measurements



'Spectrum measurement of the JET wall'



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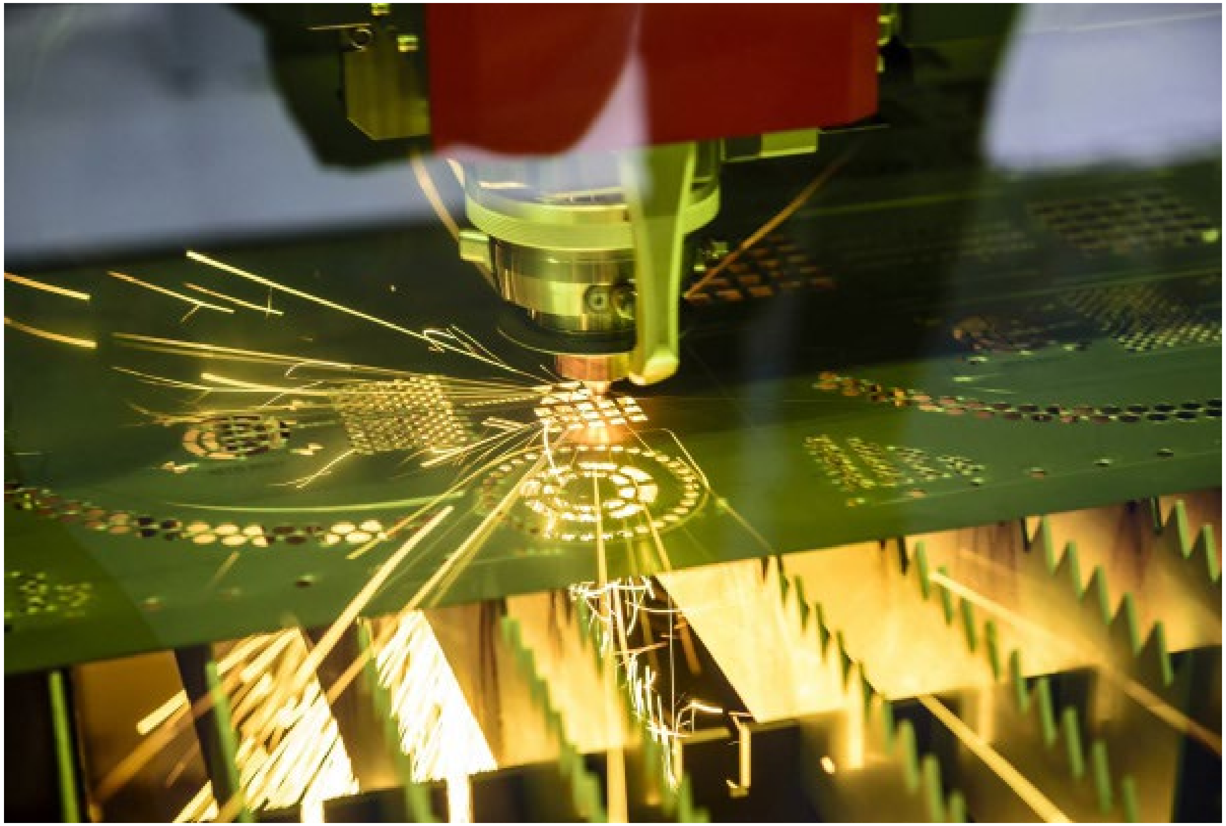
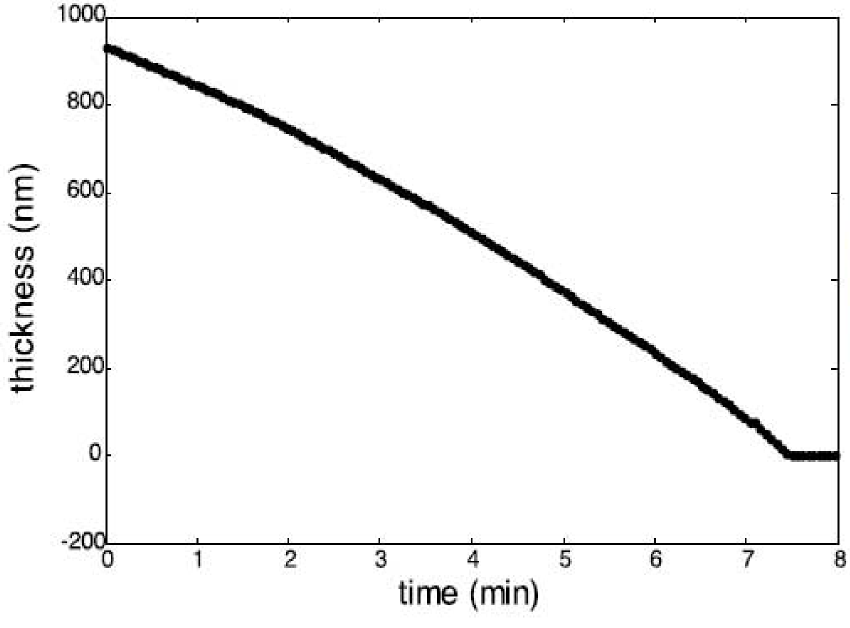
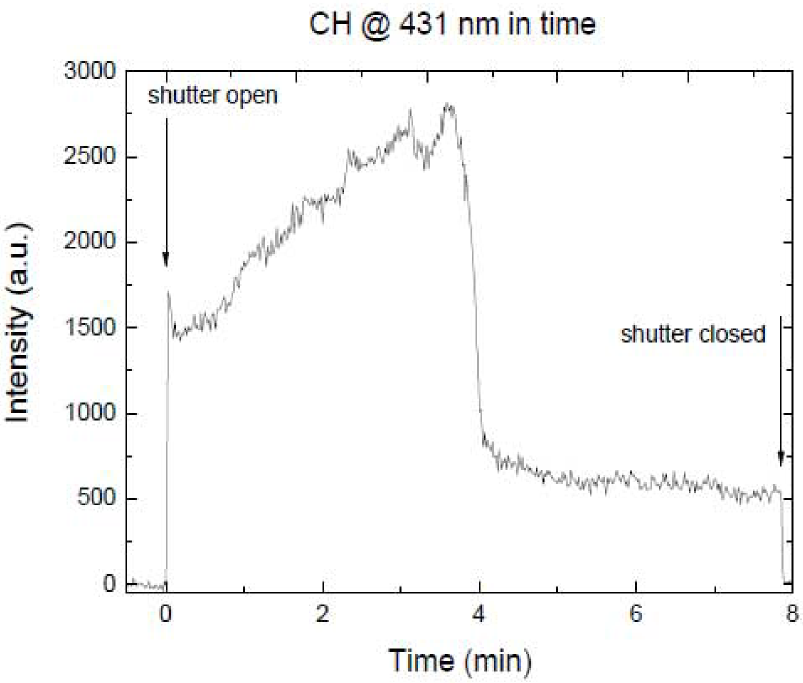


Plasma etching (Shutterstock)

Etching depth and 431 nm spectral peak intensity for monitoring CH content





Thanks for your attention!

AVANTES
solutions in spectroscopy

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