OceanOptics

Micro Fiber Optic Spectrometer Plasma Application Solution

Precise Plasma Detection Drives Cutting-Edge Manufacturing

Semiconductor/Material Preparation/Aerospace/Laser Processing/ Environmental Monitoring and Mineral Sciences

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SEMICON WEST 2025

Background introduction

Plasma is a collection of highly reactive substances composed of abundant ions, electrons, free radicals, and other extremely active species. The introduction of plasma technology in various fields such as semiconductors, material preparation, aerospace, environmental science, and chemical synthesis has led to a series of process innovations and significant technological advancements.

Plasma detection can be used to provide detailed elemental analysis of the sample and can determine the key parameters required during plasma generation. Emission lines can identify the elements present in the plasma, and the intensity of the emission line can be used to quantify particle and electron density in real time. Parameters such as gas mixture, plasma temperature, and particle density are all critical for controlling the plasma process. These parameters are changed by introducing different gases or particles into the chamber, which will affect the plasma-substrate interaction while changing the plasma properties. Monitoring and controlling plasma can improve process and finished products.

Core Principles of Plasma Detection

Excited-state particles emit characteristic spectral lines. → **Spectrometer analyze these emission lines.** → **Enables composition analysis, process control, and condition monitoring.**

Key Parameters and Technical Points of Plasma Detection

Plasma monitoring can be configured with flexible modules to detect plasma emission spectrum data, obtaining corresponding spectrum from the OceanView software.

Element Characteristic Emission Lines → **Qualitative/Quantitative Analysis**

Abrupt Changes in Characteristic Peaks → **Process Control**

Spectral Line Profiles → **Plasma Parameters**

Plasma Spectrum Detection Fiber Optic Spectrometer Series

ST Series Microspectrometers — Ultra-Compact, Seamless Integration

Delivers high-performance spectral acquisition, in an extremely compact form factor (42.1 × 40.3 × 26.6 mm), making it an ideal choice for space-constrained plasma integration systems.

- Ultra-small footprint with industry-leading miniaturized design, enabling seamless integration into plasma chambers or production line equipment for in-situ monitoring.
- Flexible configuration with three wavelength range options (UV-Vis, Vis-NIR, NIR) and changeable slits (5–200 µm) to adapt to plasma emission spectrum of varying intensities.
- Developer-friendly, includes the OceanDirect software developers kit (SDK) for easy integration into custom applications.

HR Series High-Resolution Spectrometers — Sub-Nanometer Resolution, Unmatched Precision

Offers optical resolution down to 0.06 nm, making it the preferred choice for subtle plasma spectral analysis—especially suited for applications requiring sub-nanometer resolution, such as plasma etching process monitoring.

- Ultra-high resolution distinguishes adjacent spectral lines in plasmas, preventing overlap.
- Flexible configuration covers UV-VIS-NIR ranges with changeable slits (5–200 µm) to balance resolution and throughput.
- Excellent thermal stability and stray light performance ensure data consistency during prolonged plasma detection.
- Open ecosystem support includes HSAM mode, multiple triggering modes, and the OceanDirect SDK.

QE Pro High-Sensitivity Spectrometers — Precise Capture of Weak Signals

Combines low noise, high dynamic range, and large onboard storage to cover 190–1100 nm range, making it ideal for weak-signal or UV-range plasma spectral acquisition.

- Flexible configuration with UV-VIS-NIR coverage and interchangeable slits for adaptation to diverse application needs.
- Ultra-high sensitivity, 1000:1 signal-to-noise ratio in a single acquisition with extremely low electronic noise, ensuring accurate detection of weak optical signals.
- Long integration times support measurements from ms to minutes.
- High quantum efficiency with Back-Illuminated CCD detectors achieving >90% quantum efficiency.
- Large onboard memory holds up to 15,000 spectra, ensuring data integrity during high-speed acquisition.

Ocean FX High-Speed Spectrometer — Microsecond Response, Dynamic Tracking

Delivers microsecond-level spectral response across the 200–1025 nm range, making it ideal for transient plasma detection.

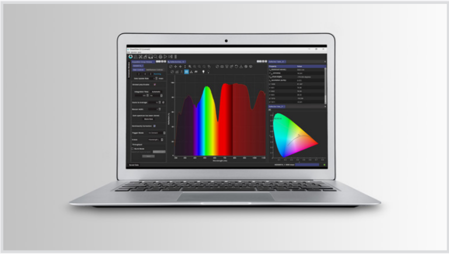
- Ultra-high-speed acquisition with scan rates up to 4,500 scans/sec to capture transient signals.
- Massive onboard memory for 50,000 spectra, ensuring data integrity during ultra-high-speed acquisition.
- Multiple communication interfaces (Gigabit Ethernet, Wi-Fi, USB) enable remote monitoring in hazardous environments, ensuring operational safety.

QP Series Extreme Solarization Resistant Fibers

High-hydroxyl material is used inside the anti-ultraviolet optical fiber, which can ensure that the signal in the ultraviolet band will not cause irreversible damage to the optical fiber itself. They enable long-term stable transmission of intense ultraviolet signals from plasma emission spectra. With micron-level sensitivity to signal variations, these fibers accurately capture transient spectral features of plasmas while preventing signal degradation caused by UV radiation damage.

CC-3 Cosine Corrector

The scattering material for the CC-3-UV-S cosine corrector is Spectralon (200-2,500 nm) , which is located at the end of the stainless steel sleeve and has a 180° field of view. it precisely captures spatially non-uniform radiation signals from plasmas and UV-resistant coating design effectively address high-intensity UV exposure.

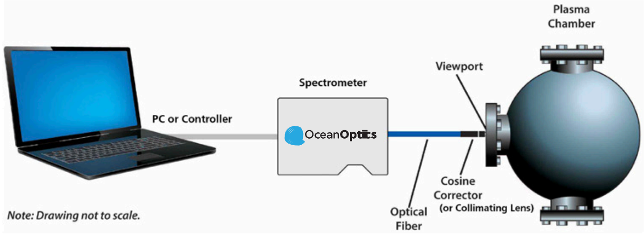


OceanView Spectral Analysis Software

OceanView software supports Windows, MacOS, and Linux systems. Equipped with extensive application wizards, it facilitates a complete analytical workflow—from raw spectral data to plasma parameters—significantly enhancing detection efficiency and data reliability in both research and industrial environment.

Industry Application|Semiconductor

In the semiconductor industry, chips are manufactured through various cutting-edge technologies involving highly precise and complex processes, among which plasma operation and control play a critical role. During plasma existence, it continuously emits energy, typically in the form of light. Analyzing plasma spectra allows for inferring plasma composition, thereby enabling monitoring and control of the reaction process.



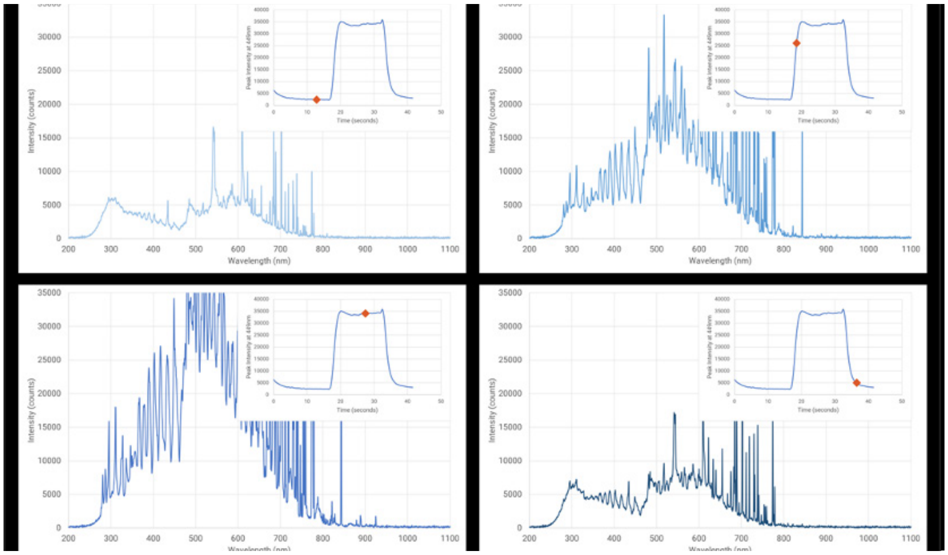
Schematic Diagram of OES for Plasma Monitoring in Vacuum Chamber

Typical Application Scenarios

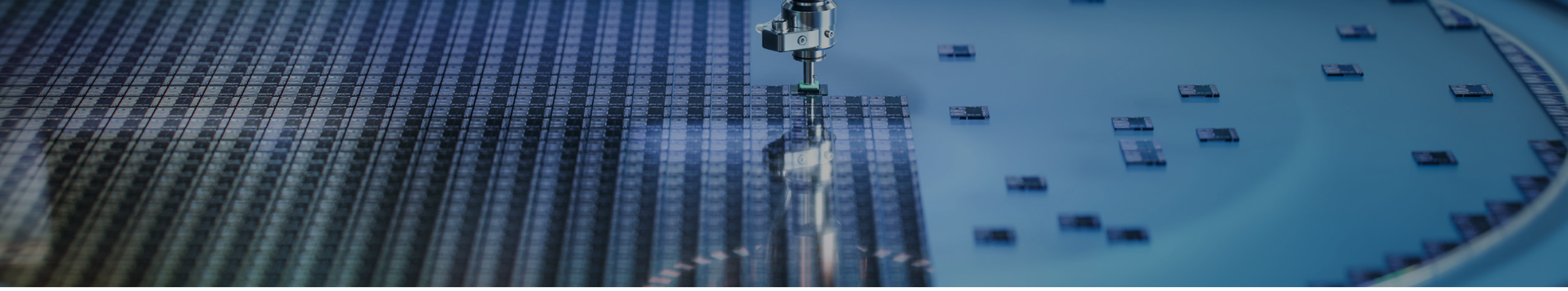
- End Point Detection (EPD) of the Etching Process
- Deposition Process Monitoring
- Plasma Temperature Monitoring
- Chamber Cleaning Process Monitoring

End Point Detection (EPD) of the Etching Process

Carbon Tetrafluoride (CF_4) plasma is commonly used to etch away layers of materials such as silicon dioxide (SiO2). Using OceanOptics HR4 spectrometer, you can accurately determine when the material has been completely removed by the O_2 content in the plasma. See below image which shows a simulation monitoring the concentration of oxygen via the intensity of emission lines between 400-600nm. In this example the O_2 levels drop to a point where the process is considered complete.

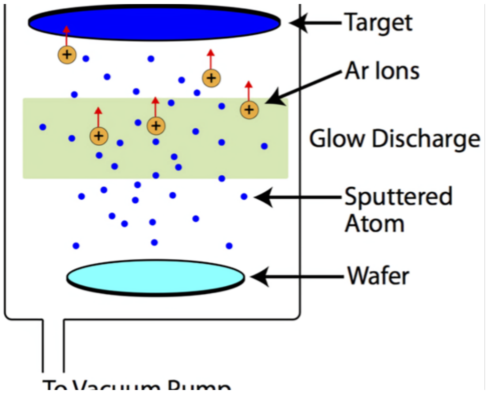


Curve of O_2 levels with etching time



Deposition Process Monitoring

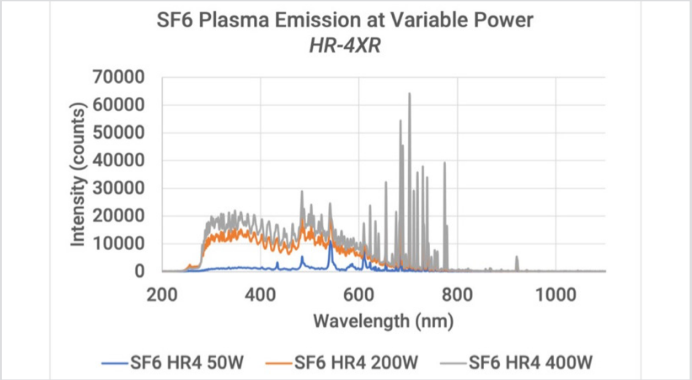
Argon plasma can ionize metal atoms, which can then be accelerated towards a wafer by an electric field, leading to a physical vapor deposition (PVD) process known as “sputtering”. Sputtering is a process where atoms are ejected from a target material due to bombardment by energetic ions. These sputtered metal atoms can then deposit onto the substrate, forming a thin film. The concentration and temperature of the Argon plasma can be monitored using OceanOptics HR4 spectrometer to determine the evaporation rate of the metal. This can then be further correlated to deposition thickness over time.



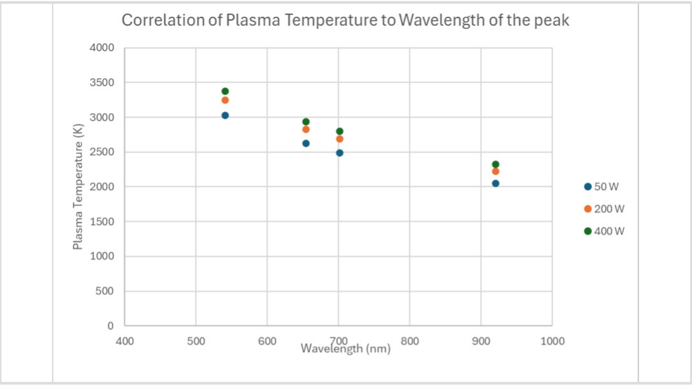
PVD sputtering chamber setup (Ar ions bombard the target, and sputtered atoms are deposited onto the wafer.)

Plasma Temperature Monitoring

The Ocean Optics HR4 spectrometer collects plasma emission spectrum from the chamber in real-time (using sulfur hexafluoride, SF_6 as an example), establishes a correlation model between emission line peak intensity and chamber power, and then be converted to plasma temperatures using the Stefan-Boltzmann equation.



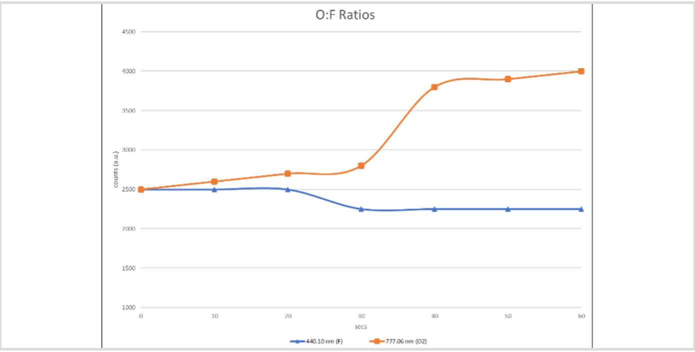
SF_6 Plasma Emission at Variable Power



Correlation of Plasma Temperature to Wavelength of the peak

Chamber Cleaning Process Monitoring

The inside of a plasma chamber can become coated with residual material during the etching and deposition processes. This necessitates the need for cleaning the chamber. This is effectively done using Fluorine-based plasmas such as CF_4 + O_2. The cleanliness levels are detected by OceanOptics HR4 spectrometer monitoring the ratio of intensities O_2 to CF_4 emission lines. A higher oxygen to fluorine ratio suggests a relatively cleaner chamber with more oxygen compared to fluorine. This could indicate that the chamber is effectively removing fluorine residues.



EN translation: Variation of the O:F ratios with time

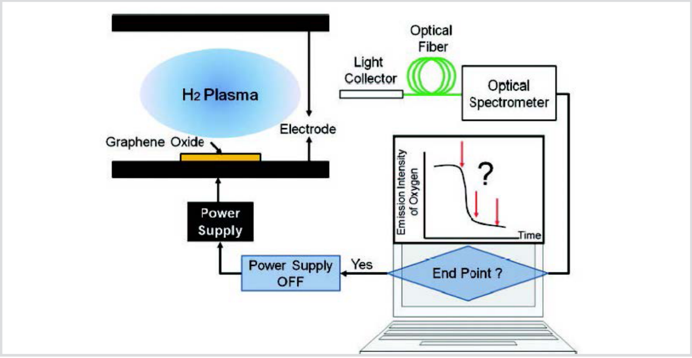
Industry Application|Material Preparation

Endpoint Detection for Plasma Reduction of Graphene Oxide

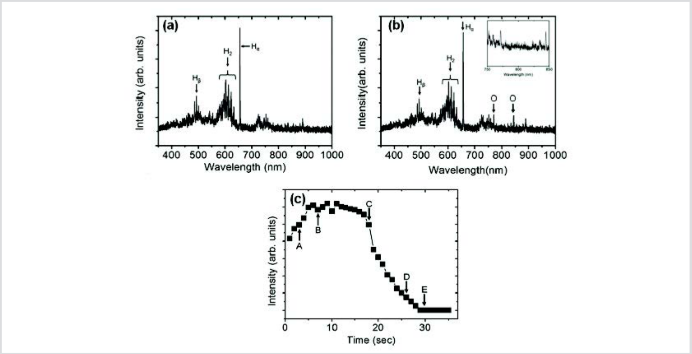
Graphene has attracted significant attention due to its exceptional mechanical, electrical, and chemical properties. However, graphene oxide (GO) itself is an insulator or semiconductor and requires a reduction process to restore its conductivity. Plasma reduction has become a research focus due to its high efficiency and controllability. However, over-reduction can damage the graphene structure and degrade its electrical performance, making real-time monitoring and precise endpoint determination critical. Using the OceanOptics USB4000 spectrometer (now upgraded to SR4), the intensity of plasma emission spectra is monitored in real-time to identify the optimal termination point for the reduction process.

Typical Application Scenarios

- Endpoint Detection for Plasma Reduction of Graphene Oxide
- Study and Process Monitoring of Carbon Nanomaterial Growth Mechanisms



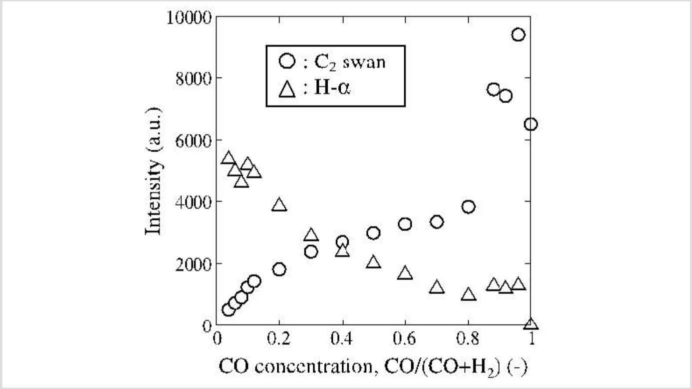
Schematic Diagram of Optical Emission Spectroscopy During GO Reduction



The emission spectrum during GO reduction shows that the optimal termination point (point C) occurs when the oxygen emission spectrum shows a declining trend.

Study and Process Monitoring of Carbon Nanomaterial Growth Mechanisms

Carbon nanomaterials (such as fullerenes, carbon nanotubes, and carbon nanowalls) have broad application prospects in electronics, energy, and catalysis due to their unique physicochemical properties. Controllable, efficient, and scalable synthesis remains a key research focus. Using the OceanOptics HR4000 spectrometer (now upgraded to HR4), the CO/(CO+H_2) ratio is monitored online, and changes of C_2 Swan band and H-α line in the plasma emission spectrum are analyzed to reflect the growth status of carbon nanowalls. By adjusting the CO/H_2 ratio, process parameters are optimized to precisely control the structure of carbon nanowalls.



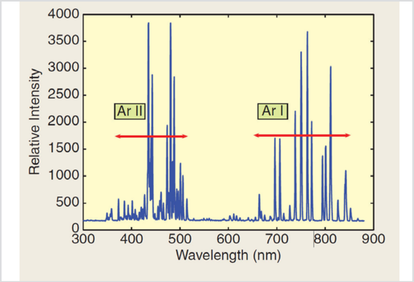
Plasma emission spectrum at different CO concentrations (CO/(CO+H_2)), The intensity variations of the C_2 Swan and H-α emission lines were observed. When the CO concentration exceeds 0.8, the C2 emission intensity increases sharply, indicating accelerated growth of carbon nanowalls.

* Superior replacement models are available for USB4000/HR4000 spectrometers. Contact Ocean Optics sales engineers for details.

Industry Application|Aerospace

Temperature Estimation for Plasma-Propelled Rocket Engines

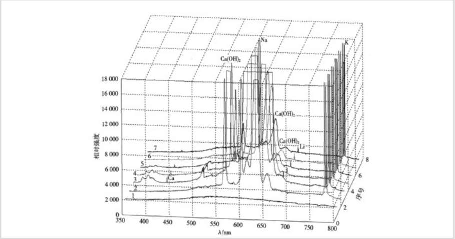
In plasma-propelled rockets (e.g., VASIMR), the high-temperature argon plasma heats the quartz tube, threatening adjacent superconducting magnets. Traditional thermocouples cannot be used due to electromagnetic interference and obstruction of cooling systems. Optical emission spectroscopy provides a noninvasive temperature monitoring by analyzing plasma emission spectrum. Using the OceanOptics S2000 spectrometer (now upgraded to SR4), plasma emission spectrum are collected to indirectly estimate the temperature distribution of the gas tube by the model of spectrum features and temperature distribution.



Argon spectrum from VASIMR. Two distinct groups of emission lines (Ar I and Ar II) can be seen on the plot. Temperature monitoring is achieved without thermocouples by processing the spectral data through Principal Component Analysis (PCA) and modeling techniques.

Real-Time Spectral Diagnostics for Liquid Rocket Engine Plumes

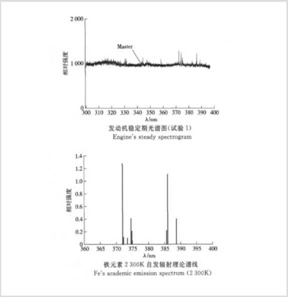
The plume generated during liquid rocket engine operation is a typical plasma containing metal ions, free radicals (e.g., OH), and other excited particles. Using the OceanOptics HR4000 spectrometer (now upgraded to HR4), UV-VIS spectrum of the plume are collected to analyze plasma composition, temperature, and engine conditions, thereby enabling fault diagnosis (e.g., metal wear monitoring).



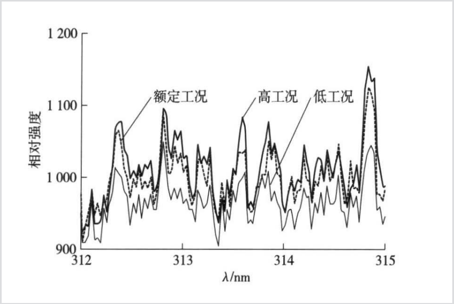
Characteristic peaks of Ca, Ca(OH)$_2$, Na, Li, and K in the visible range (422–766 nm) reflect issues such as fuel impurities, engine material corrosion, or combustion instability, providing multi-dimensional data for fault diagnosis.

Typical Application Scenarios

- Temperature Monitoring for Plasma-Propelled Rocket Engines
- Real-Time Spectral Diagnostics for Liquid Rocket Engine Plumes



Detection of five Fe emission lines in the UV band (370–390 nm) indicates iron wear inside the engine, enabling early warning.



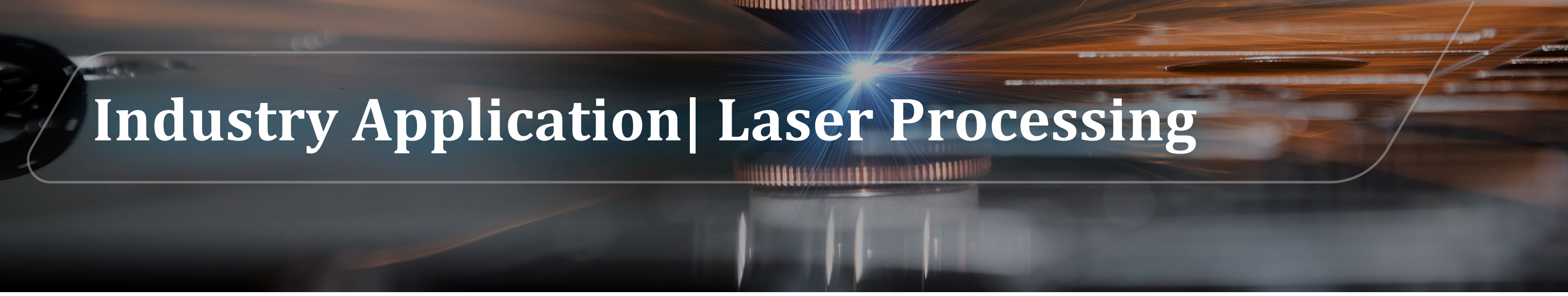
The propellant mixture ratio *k* (e.g., liquid H_2/O_2) varies under different operational conditions. By monitoring changes in the OH radical band within the plume spectrum, the engine's operational mode (high, low, or rated) can be identified to assess whether it is functioning normally.

* Superior replacement models are available for S2000/ HR4000 spectrometers. Contact Ocean Optics sales engineers for details.

References:

1. S. Lynn, et al. Temperature estimation for a plasma-propelled rocket engine [Applications of control], IEEE Control Systems Magazine, doi: 10.1109/mcs.2009.934407.

2. Q. Huang, et al. Real-time collection and analysis of UV-VIS spectrum from liquid rocket engine plumes, Journal of Beijing Institute of Technology, Vol. 28, No. 4 (2008).



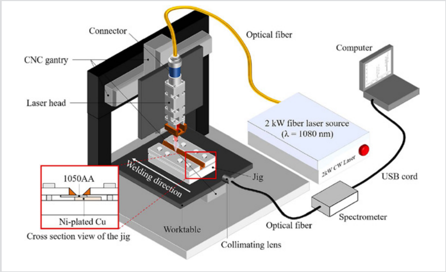
Industry Application| Laser Processing

In-situ Monitoring of Al/Cu Dissimilar Laser Welding Process

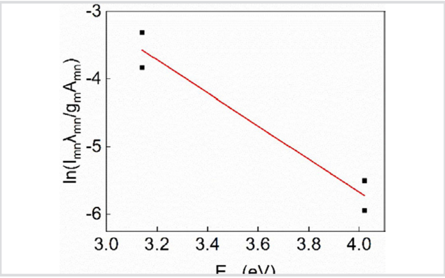
Aluminum (Al) and copper (Cu) dissimilar laser welding is an in-demand process in the manufacture of secondary battery systems for electric vehicles. However, the absence of a robust in-situ monitoring technique for this process reduces its efficiency and increases the potential risk to the battery system. Using the Ocean Optics HR2000+ spectrometer (now upgraded to HR4), the laser-induced plasma (LIP) is monitored. Plasma parameters such as emission line intensity, electron temperature, and electron density were effectively used to diagnose the welding state (non-welding, threshold welding, or Cu-penetrated welding).

Typical Application Scenarios

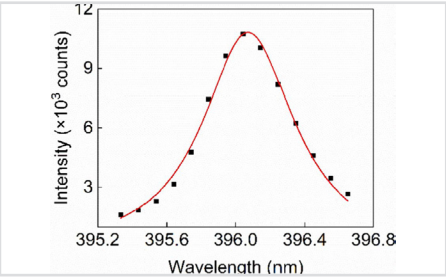
- Electron Temperature Detection
- Electron Density Detection
- Laser Welding Weld width and Depth Monitoring
- Plasma Intensity Monitoring



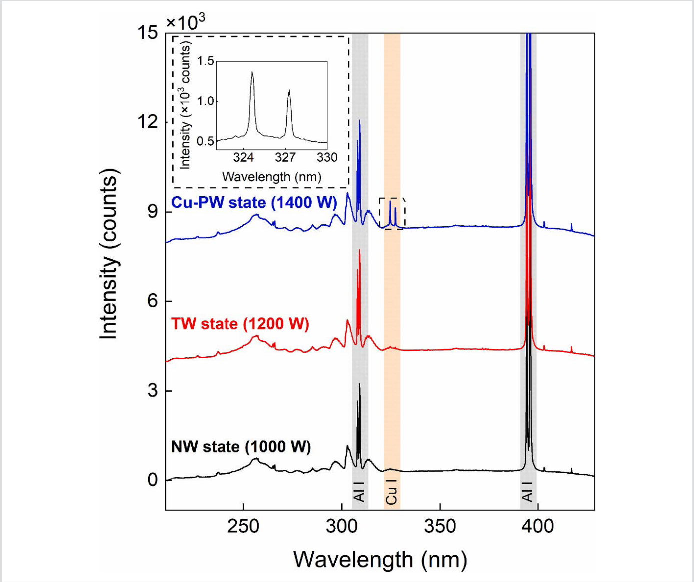
Schematic of experiment setup for laser dissimilar welding and OES.



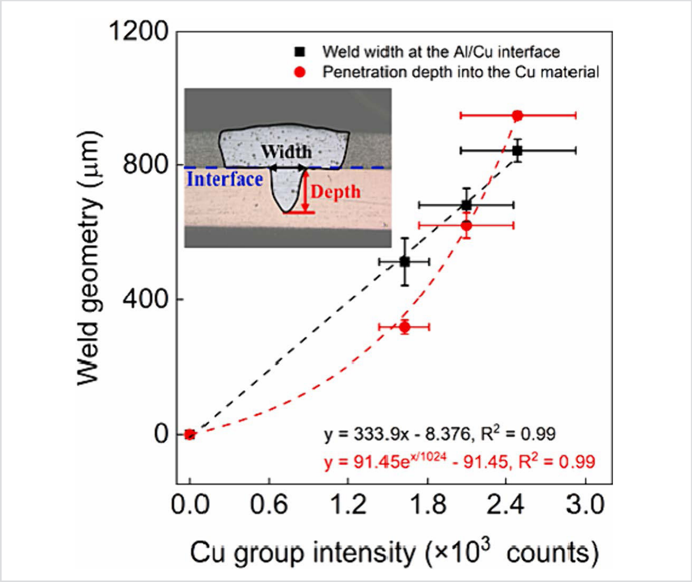
Boltzmann plot (constructed from multiple Al I emission line) to determine the electron temperature Te.



The electron density is measured by Lorentzian fit of the Stark broadened Al I line (396.15 nm).



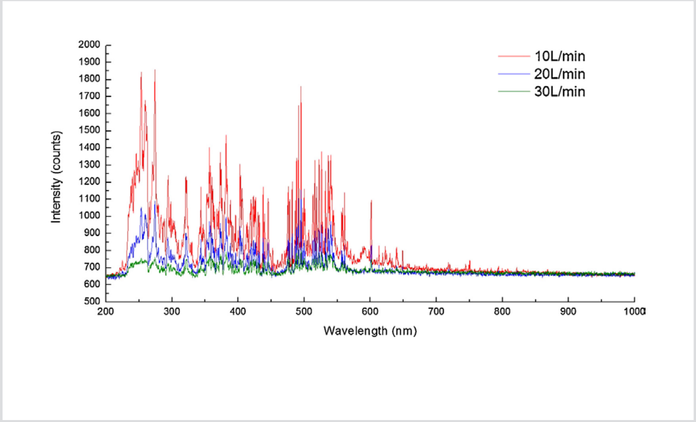
Spectral Comparison Under Three Welding Statuses (NW, TW, and Cu-pw) In the Cu-pw state, the self-reversal of Cu spectral lines disappears (the enlarged Cu I emission spectrum is shown in the top left corner), indicating that copper has been fully melted and penetrated.



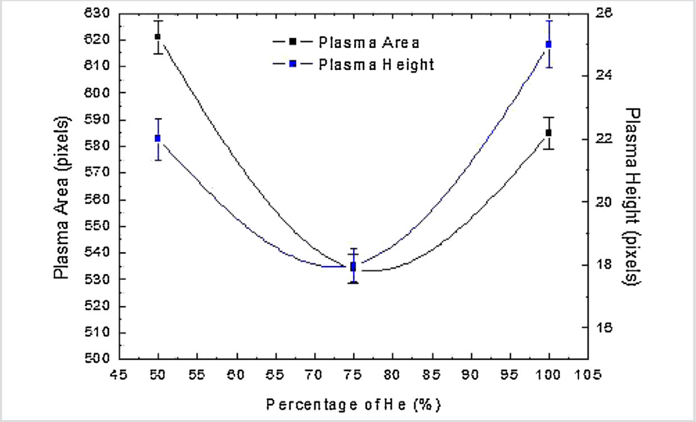
The intensity of Cu line showed a strong correlation with the weld geometry (width and depth). The weld width and depth increased linearly and exponentially, respectively, as the Cu line intensity increased

Plasma behavior and control with small diameter assisting gas nozzle during CO2 laser welding

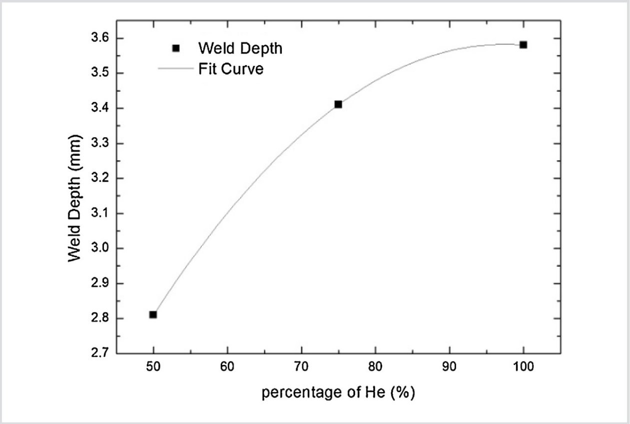
The emission spectra of CO_2 laser-induced plasma were collected using an Ocean Optics HR4000 spectrometer (now upgraded to HR4) to analyze the effects of different process parameters (gas flow rate, composition, nozzle position) on plasma intensity, stability, and laser energy absorption.



Spectrum intensity under different gas flow rate.



Area of plasma under different composition of the gas (He-Ar Ratios).



Weld depth under different composition of the gas (He-Ar Ratios).

* Superior replacement models are available for HR2000+/HR4000 spectrometers. Contact Ocean Optics sales engineers for details.

References

1. SeungGu Kang, et al. In-situ monitoring of Al/Cu dissimilar laser welding process using optical emission spectroscopy (OES), Optics and Laser Technology 176 (2024)110893

2. Yong Zhao, et al. Plasma behavior and control with small diameter assisting gas nozzle during CO2 laser welding, Journal of Materials Processing Technology 237(2016)208-215

Industry Application|Environmental Monitoring and Mineral Science

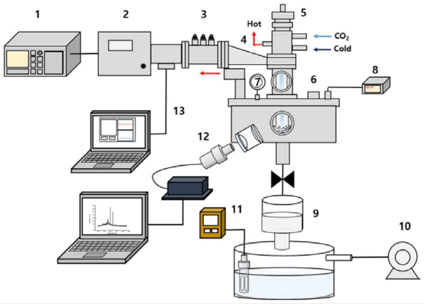
Lithium Recovery from Simulated Aqueous Solutions Using CO_2 Microwave Plasma

Lithium, a critical material for lithium-ion batteries (LIBs) and secondary batteries, has seen rapidly growing demand due to the expansion of electric vehicles and consumer electronics markets. Approximately 60% of lithium resources exist in salt lake brines. Traditional methods for lithium recovery from salt lakes or seawater (e.g., precipitation, extraction, adsorption) are often inefficient, costly, and involve lengthy processes.

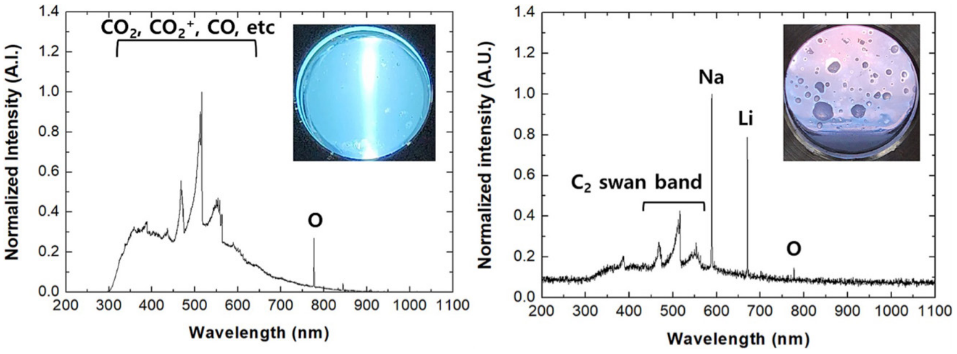
A novel, efficient, low-energy, and environmentally friendly CO_2 microwave plasma technology for lithium extraction is presented here. The CO_2 microwave plasma reacts directly with lithium-containing aqueous solutions, generating lithium carbonate (Li_2CO_3) precipitation for efficient lithium recovery. Using the Ocean Optics HR4000 spectrometer (now upgraded to HR4), in-situ detection of the CO_2 microwave plasma was conducted. By analyzing reactive species (e.g., CO, O, C_2) and plasma temperature, the role of plasma in the lithium recovery reaction mechanism was investigated. Future applications could involve real-time optimization of plasma process parameters (e.g., power, reaction time) through online monitoring of spectral features to further improve lithium recovery rates.

Typical Application Scenarios

- Lithium Mineral Detection
- Soil Heavy Metal Detection
- Water Heavy Metal Detection



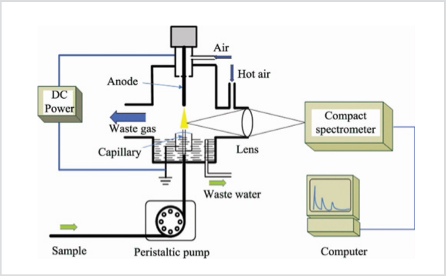
Experimental Setup: The system includes a microwave plasma generator, a plasma-aqueous solution reactor for lithium recovery, a plasma detection system, and a collection device for Li_2CO_3 products.



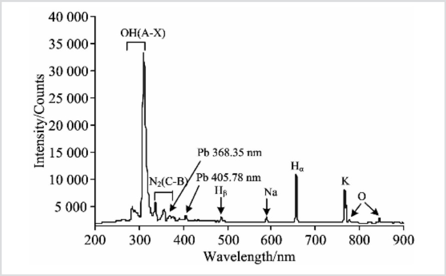
The optical emission spectra of microwave CO_2 plasma in (a) torch zone and (b) plasma–solution regions were analyzed (200–1100 nm range), clearly identifying highly reactive species such as CO_2^+, CO, O, and C_2, as well as atomic spectral lines of Na and Li from the solution. These reactive particles rapidly dissociate and ionize at the plasma-solution interface, generating OH^- and CO_3^{2-}, directly driving the carbonate mineralization reaction of Li^+ to Li_2CO_3. The plasma temperatures (approximately 2000 K in the torch zone and 1440 K in the solution zone), fitted based on the C_2 Swan band, provided an additional energy source for the carbonation reaction. These results offer theoretical support for the enhanced lithium recovery efficiency of CO_2 microwave plasma from two dimensions: reactive species generation and temperature effects. Future work could focus on real-time optimization of plasma process parameters (e.g., power, reaction time) through online monitoring of spectral features to further improve lithium recovery rates.

Heavy Metal Detection

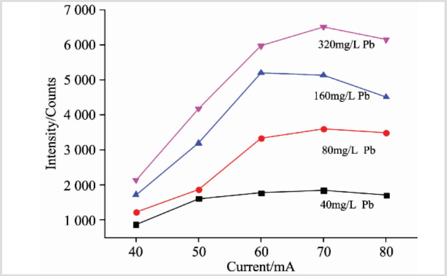
Fiber optic spectrometers enable simultaneous multi-element detection without the need for atomizers, making them suitable for on-site or laboratory miniaturized testing. They are particularly ideal for rapid, low-cost, and online detection of heavy metal elements (e.g., Cd, Cu, Pb, Cr, Zn, Na) in water/soil. Taking the detection of lead in water via atmospheric pressure liquid cathode glow discharge atomic emission spectroscopy (ELCAD-AES) as an example: the sample generates plasma through atmospheric pressure liquid cathode glow discharge, and the Ocean Optics Maya2000 spectrometer (now upgraded to HR6) analyzes the atomic emission spectra of the plasma to quantitatively determine Pb concentration.



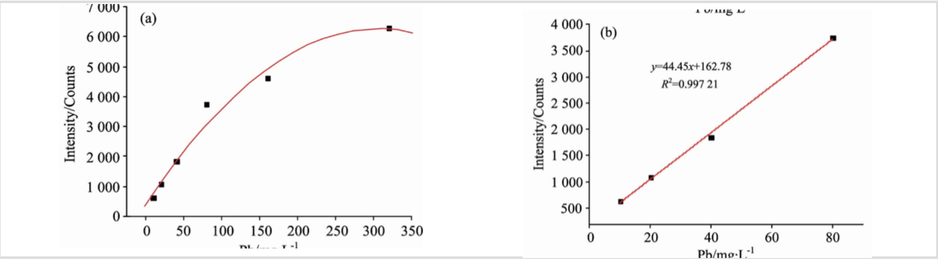
Schematic diagram of ELCAD-AES apparatus



Emission spectrum of $Pb(NO3)_2$



Effect of discharge current on emission intensity of Pb



Emission intensity of Pb at different concentration in the solution (a) 10-320 mg/L, self-absorption occurs at higher ion concentrations; (b) 10-80 mg/L

* Superior replacement models are available for Maya2000/HR4000 spectrometers. Contact Ocean Optics sales engineers for details.

References:

1. Z. Peichao, et al., Detection of Lead in water by atmospheric pressure liquid cathode glow discharge atomic emission spectroscopy, Spectroscopy and Spectral Analysis, Vol. 35, No. 7 (2015).
2. J.K. Yang, et al. Novel approach for recovering lithium from simulated aqueous solutions using carbon dioxide microwave plasma, Desalination 567 (2023) 116978

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