Application Note

Keywords

- Argon plasma
- Hydrogen gas
- Sheath gas

Techniques

- Emission spectroscopy
- Elemental analysis

Applications

- Plasma monitoring
- Endpoint detection
- Semiconductor process control

Plasma Monitoring with Miniature High-Resolution Spectroscopy

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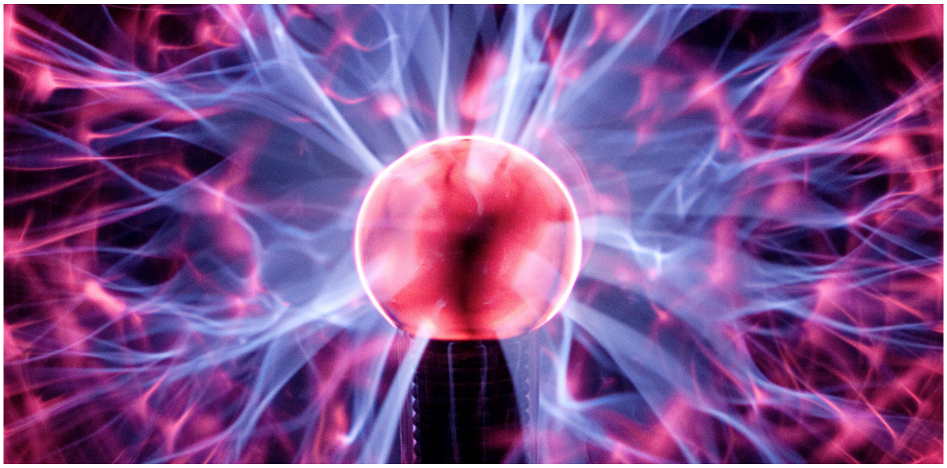
A modular spectroscopy setup based on the Ocean Optics HR2000+ high resolution spectrometer was used to monitor changes in argon plasma emission following the introduction of different gases to a plasma chamber. The measurements were done in a closed reaction chamber with the spectrometer coupled to a fiber and cosine corrector looking through a small window in the chamber. The measurements demonstrated the viability of modular spectroscopy components to acquire plasma emission spectra in real time from a plasma chamber. Plasma characteristics determined from these emission spectra can be used for monitoring and controlling plasma-based processes.

Background

Plasma is an energized, gas-like state where a fraction of the atoms have been excited or ionized to form free electrons and ions. As the electrons of excited neutrals return to the ground state, the plasma emits light at wavelengths specific to the atoms present in the plasma. The spectral profile of the emitted light is used to determine the composition of the plasma. Plasma is formed using a range of high energy methods to ionize the atoms including heat, high powered lasers, microwaves, electricity and radio frequency.



Plasma Monitoring

Plasma is used in a range of applications including elemental analysis, film deposition, plasma etching and surface cleaning. Plasma monitoring via the emission spectrum measured for the plasma sample can provide detailed elemental analysis for the sample and enable determination of critical plasma parameters required for controlling a plasma-based process. The wavelengths of the emission lines are used to identify the elements present in the plasma with emission line intensity used to quantify particle and electron densities in real time for process control.

Parameters like gas mixture, plasma temperature and particle density are all critical for controlling the plasma process. Changes to these parameters via introduction of various gases or particles to the plasma chamber will change the plasma characteristics and impact the interaction of the plasma with the substrate. The ability to monitor and control the plasma in real time leads to improved processes and products.

As an example, plasma monitoring is important for process control in plasma-based etching processes. In the semiconductor industry, wafers are fabricated and manipulated using lithography techniques. Etching is a major part of this process in which materials can be layered to a very specific thickness. As the layers are etched on the wafer surface, plasma monitoring is used to follow the etching through the wafer layers and determine when the plasma has completely etched a specific layer and reached the next. By monitoring the emission lines generated by the plasma during etching, the etching process can be followed precisely. This endpoint detection using plasma monitoring is critical to the production of semiconductor materials using plasma-based etching processes.

Plasma monitoring can be done with a flexible, modular based setup using a spectrometer like the high resolution HR2000+ or with a fully integrated system like the Ocean Optics PlasCalc plasma monitoring system. For the modular setup, the HR2000+ spectrometer could be combined with a solarization resistant fiber to acquire qualitative emission data from plasma formed in a plasma chamber. If quantitative measurements are desired for plasma control, the integrated PlasCalc system with its advanced process control systems and sophisticated data acquisition algorithms can be used.

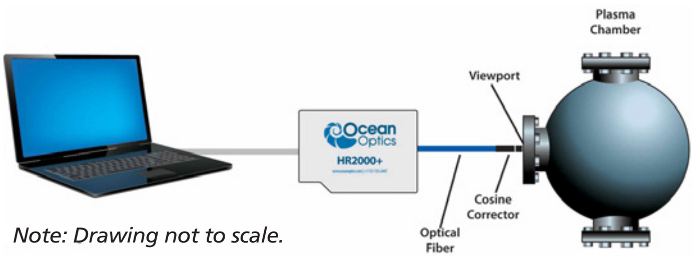


Figure 1: A modular spectrometer setup can be configured for plasma measurement in a vacuum chamber.

One important consideration when monitoring plasma formed in a vacuum chamber is the interface to the sampling chamber. Instrument components can be introduced into a vacuum chamber or set up to view the plasma through a viewport. Vacuum feedthroughs or custom fibers designed to withstand the harsh conditions in the chamber can be used to couple components into the plasma chamber. For monitoring the plasma through a viewport, a sampling accessory like a cosine corrector or collimating lens may be required depending on the size of the plasma field to be measured. With no sampling accessory, the distance from the fiber to the plasma will dictate the imaged area. For a more localized collection area, you can attach to the fiber a collimating lens like Ocean Optics' 74-UV (an f/2 fused silica lens). Cosine correctors like the CC-3-UV (Spectralon and PTFE versions are available) are also available for light collection over a 180 degree field of view.

Measurement Conditions

An HR2000+ high resolution spectrometer was used to measure changes in the emission for argon plasma as other gases were introduced to a plasma chamber. Spectral data was acquired for the plasma contained in a closed reaction chamber with the spectrometer, fiber and cosine corrector collecting emission spectra through a small window from outside the chamber (Figure 1).

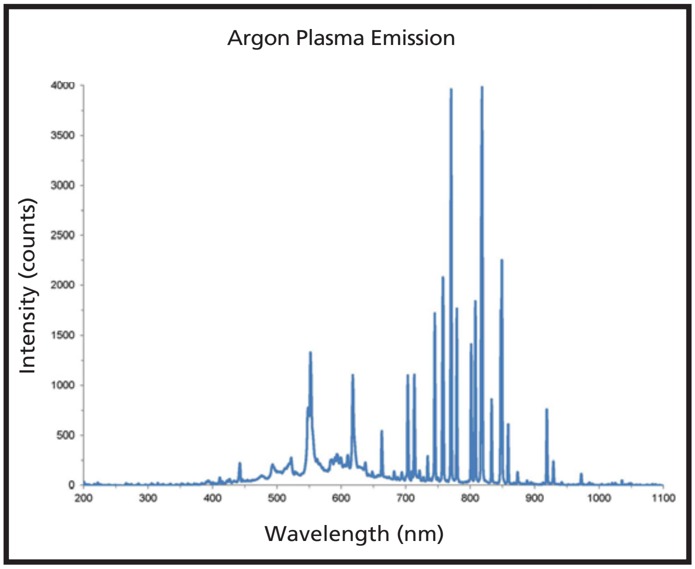


Figure 2: Emission of argon plasma is measured through a vacuum chamber window.

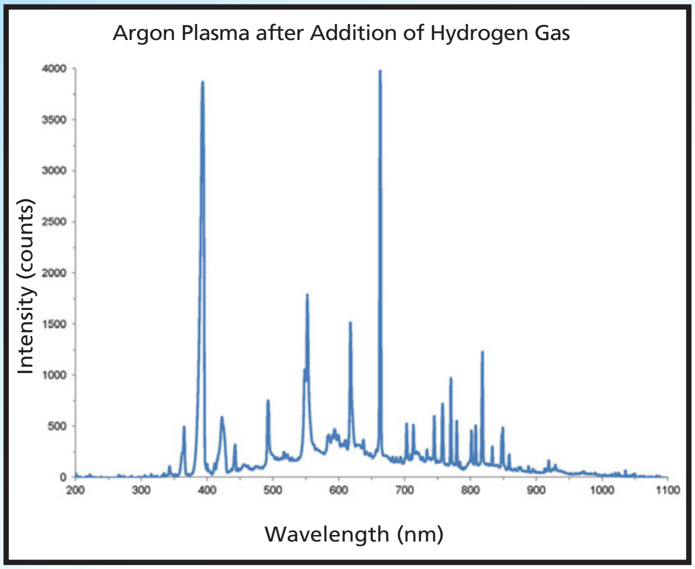


Figure 3: Adding hydrogen gas to the argon plasma changes its spectral properties.

An HR2000+ high resolution spectrometer (~1.1 nm FWHM optical resolution) configured to measure emission from 200-1100 nm (Grating HC-1, SLIT-25) was coupled to a cosine corrector (CC-3-UV) using a solarization resistant fiber (QP400-1-SR-BX fiber). A solarization resistant fiber was chosen to avoid fiber degradation caused by the intense UV light of the plasma. A CC-3-UV cosine corrector sampling accessory was chosen to acquire data from the plasma chamber to address differences in plasma intensities and inhomogeneous fouling of the measurement window.

Results

The spectrum measured for argon plasma through the window of the plasma chamber is shown in Figure 2. The strong spectral lines from 690-900 nm are emission lines from neutral argon (Ar I) with the lower intensity lines from 400-650 nm resulting from the singly ionized argon atoms (Ar II). The emission spectrum shown in Figure 2 is a great example of the rich spectral data measured for plasma emission. This spectral information can be used to determine a range of critical parameters for monitoring and controlling a plasma-based process like thin film deposition or for endpoint detection during semiconductor fabrication.

Hydrogen gas is a secondary gas that can be added to argon plasma to change the properties of the plasma. In Figure 3, the effect of adding hydrogen gas to argon plasma is shown as increasing concentrations of hydrogen gas are added to the chamber. The ability of the hydrogen gas to change the characteristics of the argon plasma is clearly shown by a decrease in the intensity of the argon lines between 700-900 nm while the increasing concentration of hydrogen gas is reflected in the appearance of hydrogen lines between 350-450 nm. These spectra demonstrate the power of measuring plasma emission in real time for monitoring the impact of a secondary gas on plasma properties. The spectral changes observed could be used to ensure the optimal amount of secondary gas is added to the chamber to achieve the desired plasma characteristics.

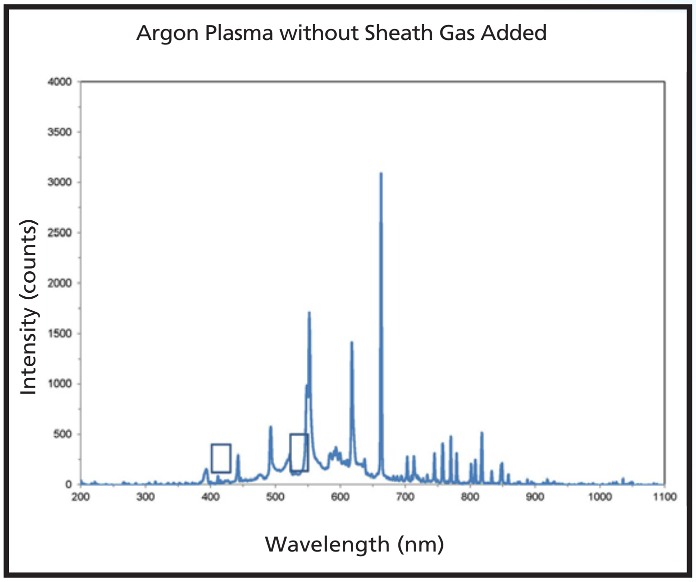


Figure 4: Argon plasma emission is measured in the vacuum chamber before the addition of sheath gas.

In Figures 4 and 5, emission spectra measured for the plasma before and after sheath gas addition to the chamber are shown. Sheath gas is used to decrease contact between the sample injector and the sample to reduce problems due to sample deposition and carryover. In Figure 4, the argon plasma emission spectrum is shown before the addition of sheath gas. The emission spectrum measured after sheath gas addition is shown in Figure 5. As shown in the figures, the addition of sheath gas leads to changes in the argon emission spectrum as seen in the loss of the broad spectral lines just below 400 nm and at ~520 nm.

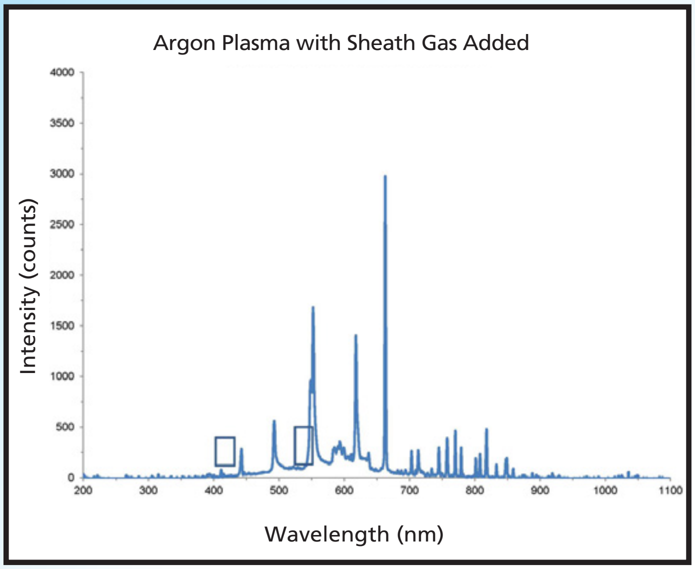


Figure 5: With the addition of sheath gas, argon emission characteristics are noticeably different below 400 nm and at ~520 nm.

Conclusion

Since emission for all elements occurs in the region from 200-1100 nm, UV-Vis-NIR spectroscopy is a powerful method for measuring plasma emission to enable elemental analysis and precise control of plasma-based processes. The data shown here illustrate the power of the modular spectroscopy approach for plasma monitoring. The HR2000+ high resolution spectrometer and modular spectroscopy approach worked well to measure plasma emission spectra through the window of a plasma chamber as chamber conditions were changed.

With an integrated system like the PlasCalc, these spectral differences could be further analyzed and used to determine critical plasma parameters to enable precise control of the conditions in the plasma chamber.