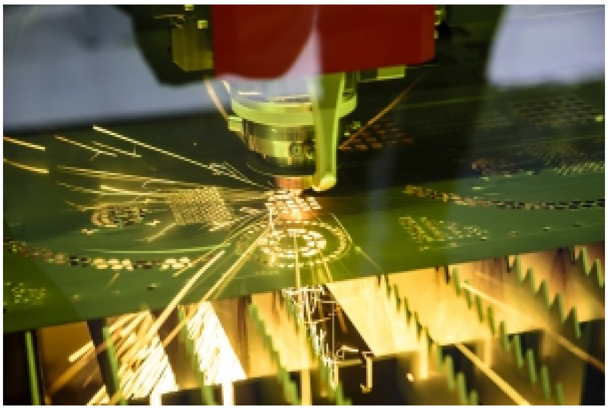
# Optical Emission Spectroscopy in the Fabrication of Integrated Circuits



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 an Avantes spectrometer 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.

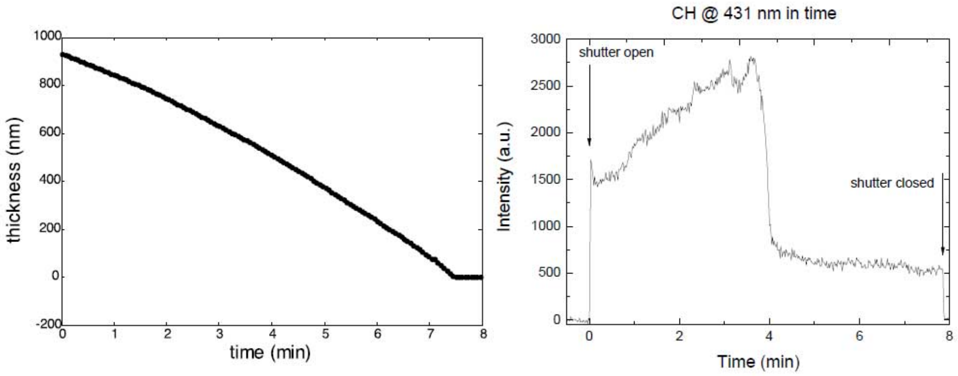


*Figure 1: Etching Depth and 431nm spectral peak intensity for monitoring CH content. Click to Enlarge*

# 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. Avantes' feedthroughs are constructed with an M12 housing, Viton® O-ring, and two SMA fiber-optic interconnects which are designed for use with fiber-optics in vacuum chambers with wall thicknesses of 5-40 mm and vacuum levels up to $10^{-7}$ millibar.

# In Optical Emission Spectroscopy, 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, Avante's miniature spectrometers are an ideal choice for this application. For example, the AvaSpec-ULS4096-EVO, from Avantes, can provide 0.05 nm resolution within the range from 200-400 nm using a 3600-grove density grating. Additionally, the AvaSpec-ULS4096-EVO 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 Avantes' 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.

# 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,

*AvaSpec-ULS4096CL-EVO*

Avantes 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 Avantes will integrate them into a custom turn-key rackmount system as shown in figure 3.

*AvaSpec Multi-channel Fiber-optic Spectrometers*

# More Applications for Optical Emission Spectroscopy

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. 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.

# Learn More About Avantes OES Capabilities

For more information about the full range of OEM spectrometer options available from Avantes, please contact us to speak with a knowledgeable applications specialist today.