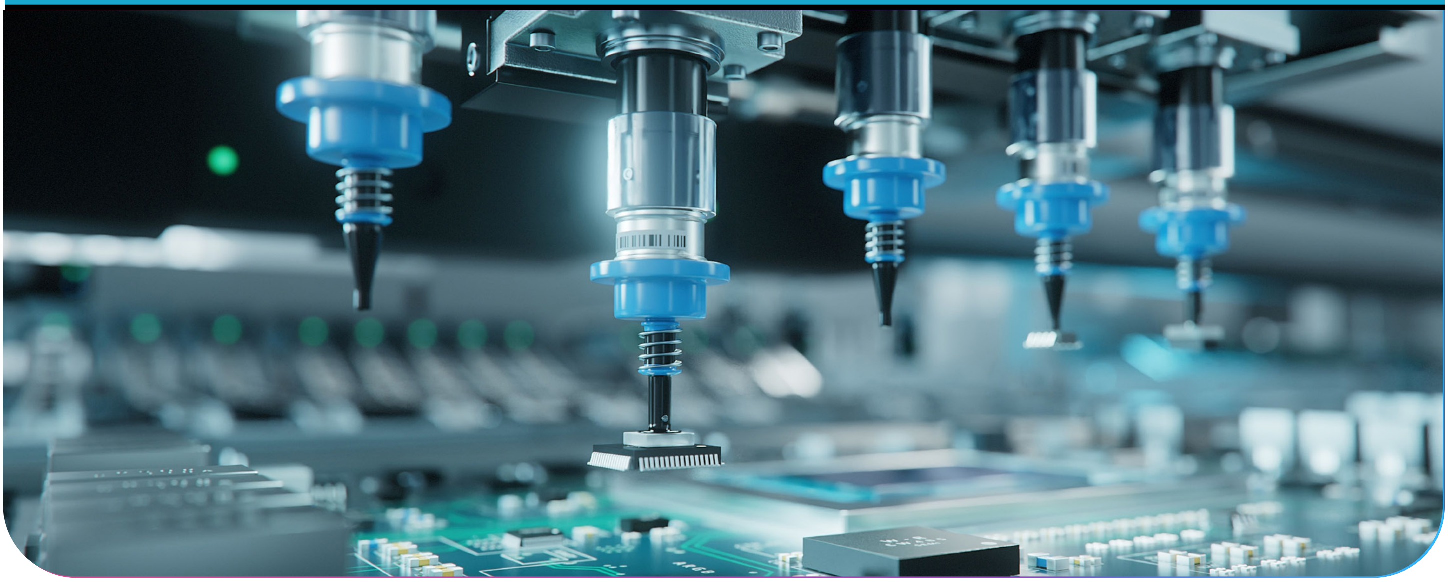
Optical Emission Spectroscopy for Semiconductor Process Monitoring and Control



Abstract:

Optical Emission Spectroscopy (OES) has emerged as a pivotal analytical technique in the semiconductor industry for its capability to provide real-time, in-situ monitoring of various processes crucial for semiconductor fabrication.

This paper reviews the principles, and applications of OES in semiconductor manufacturing processes. It discusses the fundamental principles of OES, instrumentation, data analysis techniques, and recent developments in the field. Moreover, it highlights the significance of OES in ensuring the quality, reliability, and efficiency of semiconductor fabrication processes, contributing to the advancement of technology in electronics.

Introduction

1.1 Semiconductor Fabrication Process Control

As the demand for more semiconductor products increases throughout the world, new fabs are being developed and existing fabs are being repurposed. To keep up with market demand it's imperative to get the process lines operational at the highest efficiency with minimal downtime. OES provides a cost effective and reliable way to ensure this. We will examine four different ways that OES can be utilized including.

1.) Plasma temperature monitoring
2.) End Point Detection (EPD) of the Etching Process
3.) EPD of the Deposition Process
4.) EPD of Chamber Cleaning

Fundamentals of Optical Emission Spectroscopy

2.1 Basic Principles

The 4th state of matter is an ionized gas called plasma which it emits photons as it is excited. These typically show up as narrow band emission lines at specific wavelengths. These emission lines and intensity can be monitored with an optical spectrometer configured for the spectral range and resolution of the application.

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2.2 Emission Lines and Spectral Analysis

1.) A setup like that shown in *Figure 1* can calibrated to correlate the chamber power to emission line peak intensity. See *Figure 2* as an example for Sulfur Hexafluoride (SF_6). This can then be converted to plasma temperatures using the Stefan-Boltzmann Irradiance equation like what's shown in *Figure 3*.

Figure 1

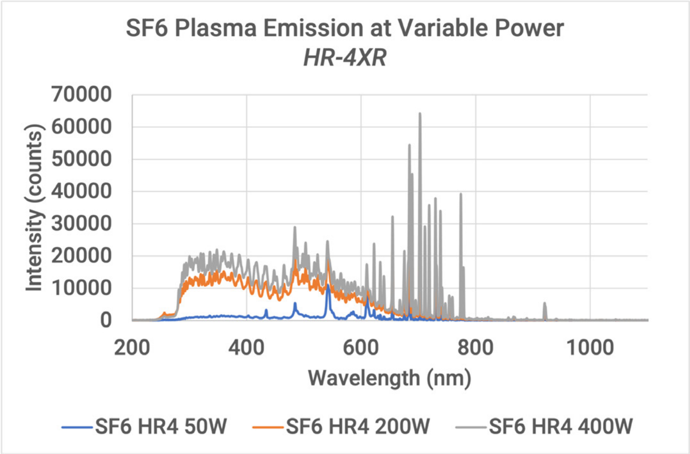

Figure 2

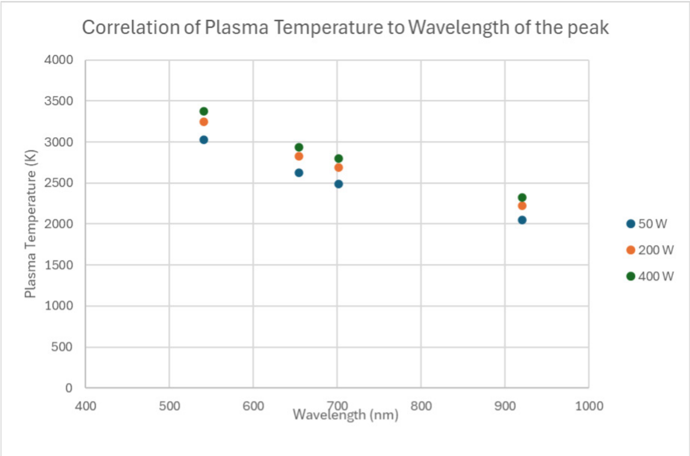

Figure 3

2.) Carbon Tetrafluoride (CF_4) plasma is commonly used to etch away layers of materials such as silicon dioxide (SiO_2). Using Time-Resolved OES, you can accurately determine when the material has been completely removed by the O_2 content in the plasma. See *Figure 4* 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.

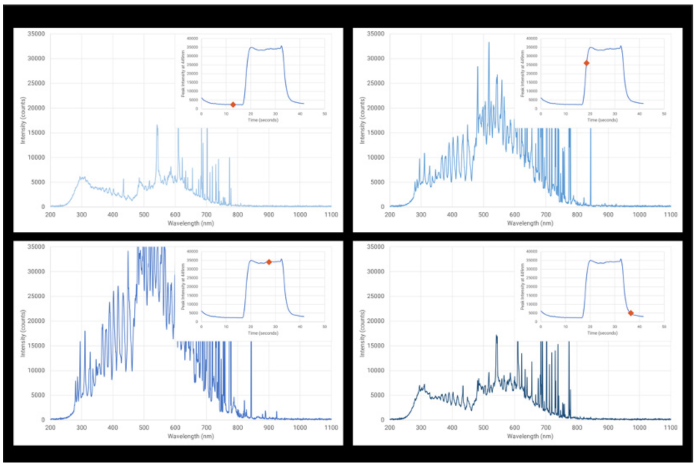

Figure 4

3.) 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. See *Figure 5* as an example chamber setup. The concentration and temperature of the Argon plasma can be monitored using OES to determine the evaporation rate of the metal. This can then be further correlated to deposition thickness over time.

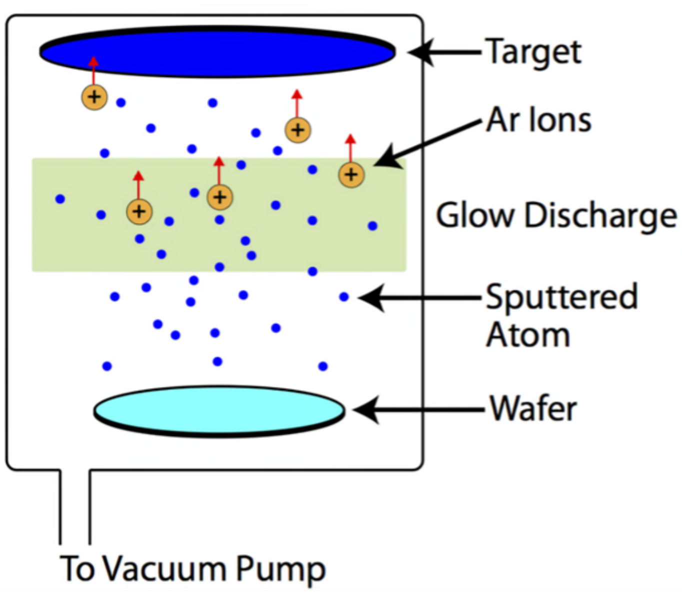

Figure 5

4.) 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 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. See *Figure 6* as an example.

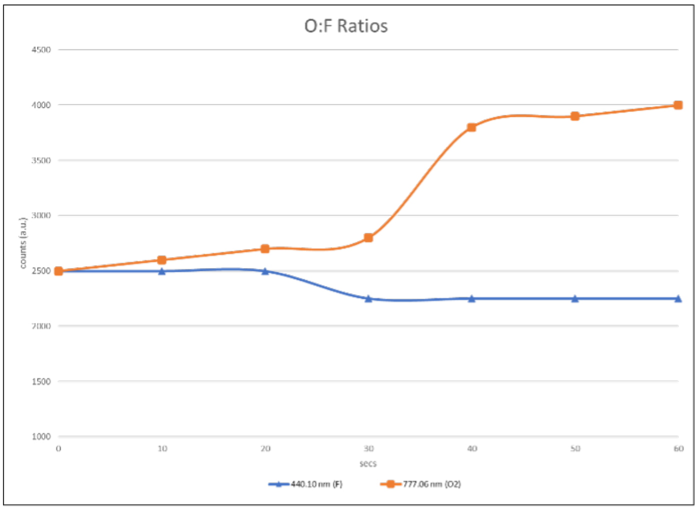

Figure 6

Conclusion

Optical Emission Spectroscopy continues to play a vital role in semiconductor manufacturing processes by enabling real-time monitoring and control. Advancements in instrumentation, data analysis techniques, and integration with other technologies are paving the way for enhanced process efficiency, quality, and yield in semiconductor fabrication. As the industry progresses towards smaller feature sizes and novel materials, OES is expected to evolve further, contributing to the continual advancement of semiconductor technology.