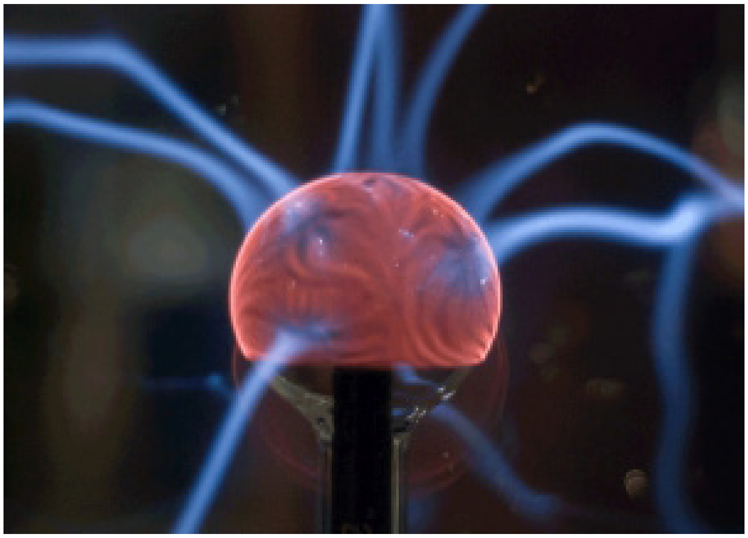
APPLICATION NOTE:
PLASMA DIAGNOSITCS AND OPTICAL EMISSION SPECTROSCOPY

Techniques

- OES Spectroscopy
- Plasma Diagnstics



Keywords

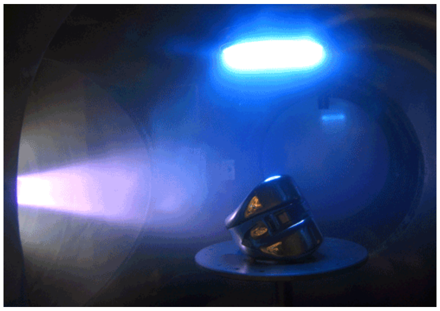
- Plasma
- Thin Film
- Optical Emission
- Space Exploration
- BioMedical

Introduction

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 example, 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 photoresist 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.



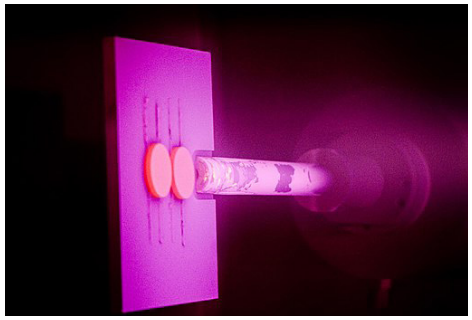
Plasma Deposition Thin Films Coatings

Thin Films and coatings are a key supporting technology within the semiconductor and solar energy production industries. A thin film is a layer or stack of layers, usually nanometers to microns thick, which are deposited on a substrate material such as a silicon wafer.

One common method of physical vapor deposition is magnetron sputtering which uses one of the noble gases like Argon which is excited to create a plasma which is in turn used to knock electrons from a cathode source to be deposited on the coated surface.

There is a great deal of interest in a particular class of plasmas called nonthermal plasmas, or atmospheric pressure plasmas in which the plasma is created at normal atmospheric pressure with the application of electromagnetic radiation. In this scenario, because the gas is not under pressure the super energized ("heated") electrons do not collide with "cold" non-energized ions or neutral particles enough to achieve a thermal equilibrium. This method of plasma creation does not require a vacuum chamber and so has lower initial cost as well as other advantages such as enabling adjustment of the plasma jet dimensions.

Researchers from Ghent University, Belgium and the Russian Academy of Science investigated surface modification of polypropylene thin films using an atmospheric pressure plasma jet generated in an Argon gas. The effects of the polymer surface treatment were dependent on the concentration of OH and H radicals generated in the discharge and measured using the AvaSpec-ULS3648 spectrometer with a resolution of 0.05 nm in the 300-350 nm region. It has been well documented that UV radiation, specifically from 306 to 315 nm, is a primary generation mechanism for hydroxyl radicals like OH and H. These researchers introduced a 0.05% water vapor into the plasma jet which increased the intensity of UV radiation and correlated to a more pronounced incorporation of oxygen into the polypropylene surface.



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In another joint research project, lead by some of the same scientists from the University of Ghent, Belgium, Changsha University, China and the Russian Academy of Science investigated the use of Nitrogen and ordinary air (78% N2/20% O2) as a plasma medium. Their method would eliminate the need for more expensive precursor gases such as Argon or Helium.

By employing a multichannel spectrometer system from Avantes, researchers performed optical emission spectroscopy to characterize the plasma discharges and determine vibrational and rotational distribution functions of electronically excited states of molecules throughout the plasma regions. This spectrometer system features the AvaSpec-ULS2048 StarLine spectrometer measuring a broadband spectral range from 250-800 nm with a resolution of 0.5 nm alongside the AvaSpec-ULS3648 high resolution spectrometer measuring from 300-350 with a resolution of 0.05 nm. They determined gas temperature in the active plasma zone through analysis of the rotational structure of a nitrogen molecule as demonstrated by the nitrogen molecular band emitted at λ 337.1 nm.

This study was able to sustain the direct current plasma jet for each gas constituent in two distinct modes, at low average current (<5mA) with the plasma self-pulsing with oscillations of current and voltage, and at high average current (> 10 mA) in which the plasma behaves as a glow discharge plasma.

Plasma Diagnostics are Essential to the Space Race

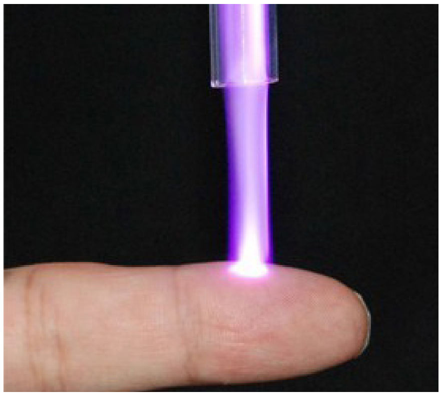
Future space exploration, and most especially any potential manned missions to Mars, require engineers to develop spacecraft capable of planet entry in varied atmospheric and gravitational conditions. During planetary entry, gases around the spacecraft are super-heated and under intense pressure, frequently generating plasma conditions. Therefore, any craft with entry capability requires thermal shielding against these conditions. The development of a thermal protection system (TPS) begins with testing design solutions using computer modeling, and eventually in real-world experiments in a plasma wind tunnel.

The Institute of Space Systems at the University of Stuttgart is home to several high-enthalpy plasma wind-tunnels (PWK1, PWK2, and PWK3, etc.) capable of simulating the atmospheric entry conditions of a Mars or Venus entry. These ground-based simulations provide a major contribution to our understanding of the aerodynamics of spaceflight by producing a continuous stream of carefully controlled plasma of high specific enthalpy and velocity by employing a thermo- or magneto-plasma-dynamic generator (TPG or MPG). In addition, the PWK3 can produce plasma tests in a variety of gasses, such as high CO2 to simulate the atmosphere or Mars or Venus, or to produce simplified conditions to investigate the effects and reactions in specific test cases of a single gas species. Furthermore, test data collected can be fed back into computational models to validate modeling results and accuracy.

Optical emission spectroscopy is the ideal non-invasive measurement technique for plasma diagnostics in the hostile environment of a plasma reaction while preventing contamination of the test conditions but requires high-resolution instrumentation. The AvaSpec-ULS3648 and new AvaSpec-ULS4096CL-EVO are our highest recommended spectrometers allowing resolution down to 0.05 nm.

Italian Aerospace Research Center (CIRA Centro Italiano Ricerche Aerospaziali)

The Role of Plasma in Medicine



Courtesy of Osaka University

One possible application for nonthermal atmospheric plasmas in medicine is for the treatment of chronic wound infections. Researchers from the Max-Planck Institute for Extraterrestrial Physics and the Institute of Pathology at the Technical University of Munich studied the suitability looked at several gas species for their effects on short-term bacterial density, long-term inhibition of bacterial growth and safety for use on human tissues. This team relied on the AvaSpec-ULS2048 to provide plasma diagnostic data and characterize the plasma emissions.

This work investigated argon plasma which emits UV radiation to provide a short-term sterilizing effect, but it can adversely affect human tissue. On the other hand, plasma generated reactive nitrogen or oxygen species demonstrate a longer-term after effect of inhibiting bacteria growth, an important factor in preventing recolonization of the wound post-treatment, and without any adverse effects on human cells.

The Future of Plasma Research

The unique properties of plasma and the many possible applications mean that research in this area will continue to lead to advancements in industry and the sciences across many fields. Avantes is prepared to support these applications with our AvaSpec instrument line and fiber optic assemblies.

Discover the next EVOlution in spectrometers, the Avantes EVO Series AS7010 electronics feature faster communication via USB3.0 or native gigabit ethernet, precise triggering, and superior signal to noise. The EVO series ideally suited to support your plasma application.

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