An Introduction to Plasma RF Generators

A plasma RF generator produces a high-power RF signal and is one of the key front-end sub-systems of a larger industrial plasma processing system. The number of applications for industrial plasma processing has exploded over the past 20 years or so, and multiple industries now benefit from using plasma processing. Some examples of these applications include:

- Semiconductor Manufacturing: Surface preparation, Vapor deposition, Etching, Thin-film deposition, and Passivation techniques
- Other Electronics Manufacturing: Surface “activation” to improve bonding, Potting, and Sealing processes
- General Industrial: To promote adhesion (surfaces), Surface hardening, Ion beam etching, and Spectroscopy
- Life Sciences: Water purification, Waste water treatment, and Bio-molecular isolation
- Medical Coatings/Cleaning: Contact lenses, Coronary stents, Artificial joints, and Medical instrument sterilization

From a physics standpoint, “Plasma” is defined as:

1. An electrically neutral, highly ionized gas composed of ions, electrons, and neutral particles. It is a phase of matter which is considered distinct from solids, liquids, and normal gases.
2. A state of matter in which some or all of the electrons have been torn from their parent atoms. The negatively charged electrons and positively charged ions move independently. Plasmas are usually associated with very high temperatures. For example, most of the sun is made of plasma.

Plasma, further defined:

Plasma is a low-density gas in which the some of the individual atoms or molecules are ionized (and therefore charged), even though the total number of positive and negative charges is equal, maintaining an overall electrical neutrality; considered to be a fourth state of matter. Strictly speaking, almost all gas in space could be called “plasma,” although only a tiny fraction of the atoms are ionized when the temperature is below about 1,000 K (726.85 ºC). The very low densities in space allow the electrons to travel without much obstruction, so (paradoxically) space is an almost perfect electrical conductor. Although charges can move around freely, averaged over even small volumes (say a million km across) cosmic plasmas are always neutral. Plasmas in space are permeated by magnetic fields. A good way to think about cosmic magnetic fields is in terms of field lines. They behave like rubber bands embedded in the plasma; so as the plasma flows, the field lines are pulled and stretched along with it. When they are stretched enough, they can pull back on the plasma. Individual electrons and ions in the plasma feel a magnetic force. This makes them travel in a helical path around the field lines, so they can travel long distances only in the direction along the field. This binds the plasma together, so that it behaves like a continuous medium (even when the individual electrons and ions almost never collide).

Usage of a Plasma RF Generator[1]

A plasma RF generator is mainly used to excite the plasma source, which in turn will provide a free-flow of actual plasma material for the application. Although many could argue that the principles of a plasma RF generator have not really changed much in the last 40-50 years or so, the main components making up the generator have certainly become significantly smaller in size. Some of the early plasma generators that used nitrogen or air required at least 5–10 kW of power to sustain the plasma discharge. They also literally (physically) took up half the room. Most of today’s plasma RF generators use solid state electronic components. This makes modern plasma generating instruments significantly smaller and far more suitable for routine operation.

An important consideration in plasma RF generation is the RF power coupling efficiency between the RF generator power

An Introduction to Plasma RF Generators (cont.)

amplifier stage and the plasma itself. For Inductively Coupled Plasma (ICP) generation, the majority of modern solid-state RF generators are on the order of 70–75% efficient, meaning that 70–75% of the delivered power actually makes it into the inductive coil exciting the plasma.

When a plasma RF generator is used for Inductively Coupled Plasma - Mass Spectroscopy (ICP-MS), another important criterion to consider is the way the RF amplifier's output impedance matching network compensates for changes in impedance produced by the sample-under-test's matrix components or differences in solvent volatility. In older crystal-controlled generators, this was usually done with servo-driven capacitors. They worked very well with most sample-under-test types; but because they were mechanical devices, they struggled to compensate for very rapid impedance changes produced by some samples. As a result, large momentary impedance mismatches could reflect too much of the RF power, and the plasma was easily extinguished. This happened often in ICP-MS processes, particularly during aspiration of volatile organic solvents.

These problems were partially overcome by the use of free-running RF generators, in which the matching network was based on electronic tuning of small changes in frequency brought about by the sample solvent or matrix components. The major benefit of this approach was that compensation for impedance changes was virtually instantaneous because there were no moving parts. Most high-end systems today use some sort of dynamic, controllable impedance matching network between the RF amplifier and the plasma source. Another important design consideration is to make sure that the RF power transistors used in the final amplifier stage are very rugged – that they can withstand and survive a large mismatch.

Modern Uses for Industrial Plasma Processing Systems

Richardson RFPD offers a wide assortment of active and passive RF components to OEM equipment manufacturers designing RF generators for most plasma processing applications:

Coating of plastic films
Diamond film deposition
Gas chromatography
High-Intensity discharge lamps
Ion - Assisted deposition
Ion beam etching
Ion beam milling
Ion Implantation
Large area coating
Low pressure plasma
Plasma - CVD/PVD
Plasma drilling
Plasma etching
Plasma hardening
Plasma spectroscopy
Plastic lens coating
RIE - Reactive ion etching
Surface cleaning
Thin film deposition
UV lamps
Waste Treatment
Water Purification

Sources

1. Much of this section was paraphrased from the tutorial, "A Beginner's Guide to ICP-MS [Inductively Coupled Plasma – Mass Spectroscopy], Part III: The Plasma Source," by Robert Thomas (2001).