RF antennas as plasma monitors

A. A. Howling[1]*, Ph. Guittienne[2], I. Furno[1]

[1]Centre de Recherches en Physique des Plasmas, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland
[2]Helyssen, Route de la Louche 31, CH-1092 Belmont-sur-Lausanne, Switzerland
*Contact e-mail: alan.howling@epfl.ch

1. Introduction

The measurement and control of plasma parameters such as electron density are of prime importance for successful plasma processing. This is particularly critical for advanced process control of etching and deposition reactors.

This abstract reviews the literature concerning radio-frequency (RF) antennas for plasma monitoring. Recent novel developments will be reported in the accompanying invited talk.

2. RF antenna diagnostic types and methods

In order to determine the electron density n_e, RF antenna diagnostics generally measure the electron plasma frequency $\omega_{pe} = (n_e e^2/(m_e \varepsilon_0))^{1/2}$ either directly, or indirectly via the plasma relative permittivity $\varepsilon_r = 1 - \frac{\omega_{pe}^2}{\omega^2\left(1 - j\frac{\nu_m}{\omega}\right)}$, where $j = \sqrt{-1}$, and ν_m is the electron-neutral collision frequency.

Cut-off probes rely on the detection of the cut-off frequency for electromagnetic (EM) wave propagation in the plasma, which coincides with the electron plasma frequency. Generally, this kind of measurement implies the use of a pair of antennas: the first emits a signal in one region of the plasma while the other is used as a receptor [1]. This technique usually monitors only the electron density which is estimated from the measured electron plasma frequency, although sheath thickness and electron collision frequency can be estimated using appropriate circuit models.

The family of plasma resonance spectroscopy probes [2,3] (including active plasma resonance spectroscopy, multipole resonance probe, the plasma absorption probe, and the curling probe) uses the phenomenon of plasma resonance at or near the electron plasma frequency. In contrast to cut-off probes, these probes use a one-port arrangement where a network analyser measures the reflection coefficient as the probe frequency crosses the electron plasma frequency.

The electron density can be measured by the interferometry method, for which the diagnostic frequency is greater than the cut-off frequency so that the radiation can propagate in the plasma. In this case an EM wave (typically >10 GHz) is launched through the plasma and mixed with a reference signal. The resulting phase shift between the two signals depends on the line-averaged plasma density and on the chord length of the sampled plasma slab. Another variation, called Lecher wire interferometry [4] guides the EM wave through the plasma along two thin wires which join the opposing waveguides.

The microwave cavity technique uses the fact that the cavity's resonance frequency depends on the permittivity of the medium inside the cavity to measure the electron density. The frequency shift caused by the plasma is related to the free electron density weighted over the spatial distribution of electric field [5]. Typically, the plasma reactor is designed as a cylindrical cavity with a single resonant mode.

Another technique to extract the plasma density is also based upon measuring the cold plasma permittivity. A resonant structure is directly inserted into the plasma and the shift in the resonance frequency is measured, which depends upon the plasma dielectric constant. In the original design [6], the resonator consists of a 1/4 wavelength parallel-wire transmission line section with one shorted and one open end. In vacuum, the quarter wavelength resonator exhibits a resonant frequency, typically in the GHz range. When immersed in a plasma, the frequency shift with respect to the vacuum provides the plasma frequency, hence the electron density averaged over the volume penetrated by the electric field of the resonator.

We will investigate the potential for other types of RF antenna designs and different techniques for plasma diagnostics.

References

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