Elementary microwave plasma sources with extended operating parameters: concept, design and performance. Examples of applications in low and very low pressure range.

P. Baele[1,2], T.L.Phan[1], A. Todoran[1], C. Prahoveanu[1], A. Lacoste[1,3]

[1]LPSC, Université J. Fourier Grenoble 1, CNRS/IN2P3/INSIS, Grenoble INP, 53 rue de Martyrs, 38026 Grenoble Cedex, France
[2]Thales Electron Devices, 2 rue M. Dassault, 78140 Velizy-Villacoublay, France
[3]ana.lacoste@ujf-grenoble.fr

Based on an opened coaxial structure, microwave applicators (MWA) were developed in order to meet two main requirements: i) breakdown and sustainment of microwave plasma in a range as wide as possible of operating conditions (10^{-4} Torr to few Torrs of pressure, and 1 W to few hundred watts of microwave power at 2.45 GHz in the present case); ii) upgrading the power transmission efficiency through MWA and the electron heating efficiency without the use of an impedance matcher in the feed system.

To address the first requirement, especially to enable the sustainment of plasma in the very low pressure range, the MWA is provided with a magnetic structure in its end part (at the side of plasma generation), its role being gradually reduced as the pressure increases. In other words, the MWA configuration ensures a continuous passage from local resonant absorption (electron cyclotron resonance ECR, $\omega_{ce} = \omega$) at low pressure ($\nu \ll \omega$) [1] to collisional absorption [2] of the MW power by the electrons, when $\nu \geq \omega$ (ν is the frequency of electron collisions for momentum transfer). The scanning over large pressure and power range allows the measurement and determination of plasma impedance (disconnected from the impedance of the MWA excitation system) for different plasma parameters (ν/ω, ω/ω_{pe}). The obtained results clearly show, on the one hand, the existence of capacitive-inductive transition modes [3], and, on the other hand, the opportunity to achieve 100% of transmission and heating efficiency when the surface impedance at the output of MWA is equal to the plasma impendence. The precise knowledge of the plasma impedance provides the ability to design microwave applicators directly adapted to a predefined window of operating parameters, thereby obtaining an increase of energy efficiency of the applicator, and even preventing any reactive coupling into the plasma.

Performance in terms of plasma density of each elementary plasma source, as well as their flexibility and scaling-up capability carried out by the distribution of elementary sources over two- or tri-dimensional networks, open the way to many applications requiring high density plasma and uniform plasma of large area or volume. Following the presentation of some characteristics of plasma sources such as impedance, coupling modes, energy efficiency, plasma density, some examples of applications will be given and discussed. It concerns examples of an elementary source operating in low power-medium pressure range (P < 30 W, p ~ 1 Torr), or also of assembled sources for applications requiring very low pressure (surface cleaning, deposition of complex alloys with perfectly controlled stoichiometry).

Keywords: elementary microwave plasma source, plasma impedance, coupling modes, plasma processing

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