2.45 GHz plasma sources using solid state generator: design and comparative performance of ECR- and Collisional-type sources in matrix configuration

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Large-scale processing with high density and uniform plasma is necessary for surface treatments that need highly uniform etching or deposition rates. To meet these industrial requirements two kind of sources were designed: the first one is an Electron Cyclotron Resonance-type coaxial microwave plasma source called *Aura-Wave* where plasma may be sustained from 10^{-4} mbar up to a few 10^{-1} mbar and reaching plasma density up to a few 10^{11} cm^{-3} in multisource configuration at 10 cm from the source. The second plasma source is a collisional-type coaxial source called *Hi-Wave* where plasma may be sustained in a more restricted pressure range, i.e. 10^{-2} mbar to a few 10^{-1} mbar, but allowing plasma densities higher than 10^{12} cm^{-3} in multisource configuration at 10 cm from the source. This was achieved with a solid state generator which produces a wave with variable frequency, a feature used to automatically compensate the low mismatching that might be created by changes in the operating conditions. Furthermore, both sources set up with a matrix arrangement were proven to produce large, uniform and high density plasma without scale limitation.

1. Introduction

The concept of distributed coaxial plasma sources in matrix configuration where several dipolar plasma sources excited at 2.45 GHz was introduced as far back as 2002 by Lacoste et al. [1]. The main idea of the distributed sources was to assemble as many elementary plasma sources as necessary in order to achieve uniform and high density plasmas, satisfying the need for large scale surface treatment processes – e.g. surface etching, coatings, diamond deposition, biomedical treatment etc.

In order to meet the industrial need in large scale processing with highly uniform and efficient surface treatment rates, coaxial antennas may be used as elementary plasma sources. In our work, two kind of sources were designed: the first one is an Electron Cyclotron Resonance-type coaxial microwave plasma source called *Aura-Wave* [2] and the second plasma source is a collisional-type coaxial source called *Hi-Wave.*

Both sources were designed to avoid power losses and to be used without any tuning system. Sources are arranged in matrix configuration; each source is connected to its own microwave solid state generator which produces a wave with variable frequency. This feature can be used to automatically compensate the low mismatching that might be created by changes in the operating conditions [3]. This industrial set-up allows the control of transmitted microwave power to each plasma source with one watt increment and thus, having a full control for a wide range of processes.

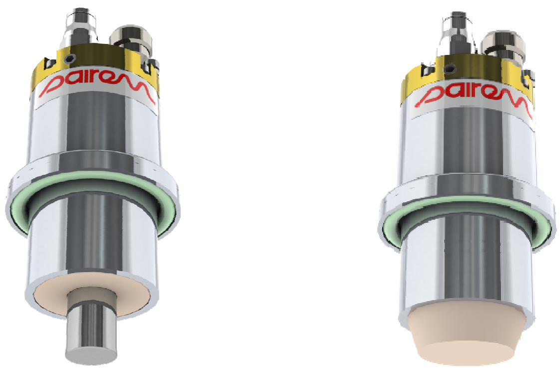
In this paper, each source-type performance in different gases has been evaluated as a function of pressure and microwave power. Optical emission spectroscopy and Langmuir probe analysis were performed in order to compare emissions of reactive species and plasma density of each plasma source-type. We have also worked on the system optimization in order to reach uniform plasma over large treatment areas; plasma density profiles were measured and results have proven that both sources allow to produce large, uniform and high density plasma without scale limitation.

2. Plasma source design

2.1 Aura-wave source

At low gas pressure microwaves combined with a static magnetic field can result in highly efficient electron heating mechanism. When the electron cyclotron resonance frequency to the applied electromagnetic wave frequency, resonance occurs resulting a highly efficient electron heating mechanism.

Our coaxial antenna exploiting the cyclotron resonance consist in encapsulating cylindrical permanent magnets within the coaxial structure. The source called *Aura-wave* has been designed (cf. Figure 1) to be self-adapted once the plasma ignited, sustaining plasmas from 10^{-4} mbar up to a few 10^{-1} mbar and reach plasma densities up to a few 10^{11} cm^{-3} in multisource configuration at 10 cm from the source.



(a) (b)

Figure 1: Aura-source (a) and Hi- source design (b)

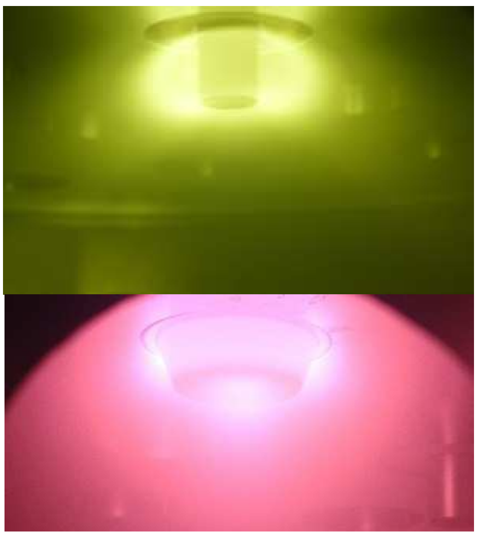


Figure 2: Plasmas generated with *Aura-wave* in O_2 at 190 W (above); and with *Hi-wave* in air at 200 W (below)

2.2 Hi-wave source

The first design based on electron cyclotron design is well suited when the electron collision frequency is small compared to the ECR frequency, thus for low pressure (10^{-4}~10^{-1} mbar) plasma generation. At higher pressure, the collision frequency is higher, decreasing ECR heating mechanism efficiency. The second source was therefore designed magnet free and to be self-adapted in the collisional regime at higher pressure range (10^{-2} mbar ~ 10^{-1} mbar), and allowing plasma densities higher than 10^{12} cm^{-3} in multisource configuration at 10 cm from the source.

3. Experimental characterization

3.1 Experimental setup

The characterization in multisource configuration was performed in a cylindrical with a diameter of 500 mm and height of 400 mm. Up to 16 sources arranged in a square lattice – with the step size *a* – may be put on the upper side of the chamber (cf. Fig. ###). Each of them is independently fed by a solid state MW generator capable of furnishing up to 200 W. The independent power tuning of each plasma source is a major advantage in obtaining highly homogenous plasma as the power input at the periphery may be modulated in order to compensate losses due to wall recombination.

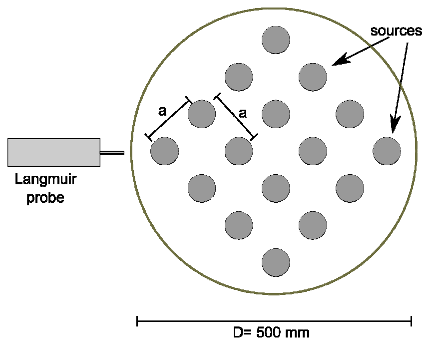


Figure 3: Top view of characterization setup in multisource configuration. Sources are distributed in square lattice with step size of *a*. The Langmuir probe was placed at 160 mm from the top.

The obtained plasmas with different coaxial sources and different network distributions were diagnosed with a Langmuir probe placed at several heights. Motorized linearly with a step motor, a spatial resolved of plasma parameters were obtained, allowing the plasma uniformity evaluation in terms of density and temperature.

The probe used was made of two cylindrical tungsten tips (*Ø230* µm in diameter and *12* mm in length): one for current–voltage (*I-V*) acquisition and the other served as a reference electrode for noise reduction and probe circuit impedance compensation. Data acquisition and analysis were carried out with Impedans ALP SYSTEM™.

In parallel, the plasma optical emission was canalized through a 200 µm fiber optics and measured with a spectrometer (Avantes Avaspec 2048-2) in the 200–1000 nm range.

3.2 Preliminary results in *Aura source*

Typical images of plasmas obtained with the two types of coaxial source in matrix configuration presented in this paper are shown in Figure 4. The visual aspect of the plasma emission reveals the main plasma production area. For the Aura source case, the intense emission assimilated to plasma production zone concord quite well with the ECR surface at 2.45 GHz; whereas for the High-wave source, the plasma emission decrease with relative progressiveness away from the coaxial dielectric surface which indicate progressive microwave absorption.

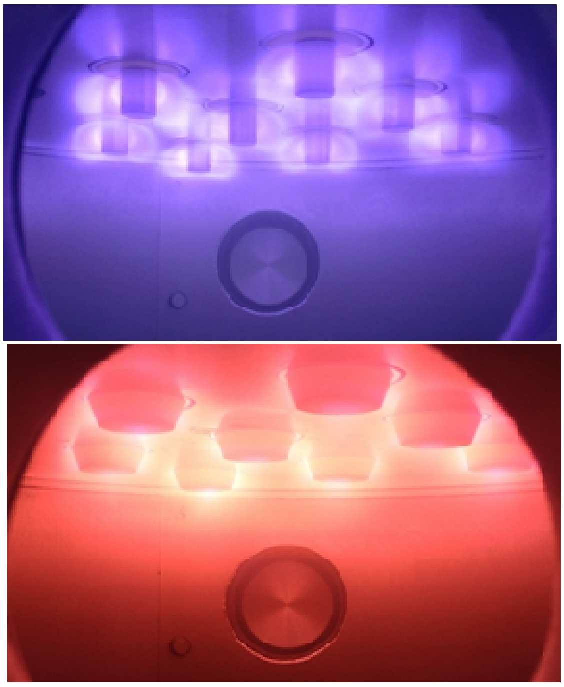


Figure 4: Images of 8 Aura-Wave sources ignited in Argon at 10^{-2} mbar each with 20 W power input (above); and , 8 High-Wave sources ignited in N_2 at 10^{-1} mbar each with 200 W power input (below).

An example of plasma density characterization for Aura sources is shown in Figure 5. Radial measurements were performed at h = 160 mm from the sources and the figure compares the plasma density radial variation between cases when each source was ignited independently and the case when the three of them was ignited all together. It was shown that the profile remained constant over 200 mm of distance. Furthermore, the resultant profile was found to be merely the algebraic sum of each source density profile contribution. This is a crucial point which permit an extrapolation of a single source density profile measurement to *n* number of sources profile. We may therefore expect attaining much higher plasma density and uniformity, for a large area.

In figure 6, an example of theoretical distribution of 8 Aura-wave sources aligned horizontally. A step size of 175 mm separate them from each other and the density profile was calculated at a distance of 160 mm below the source plan. The summation of all the density contribution showed that a ripple rate below 2 % over 1 meter in distance may be achieved.

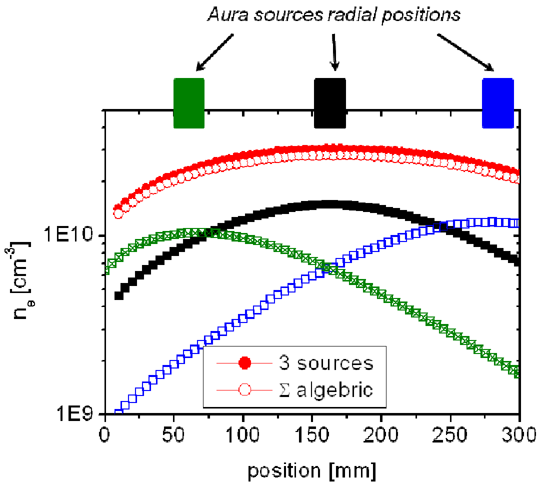


Figure 5: Electronic density profile with three sources ignited separately (from left to right: green, black and blue) and all of them (in red filled symbols). The algebraic sum is in red empty symbols.

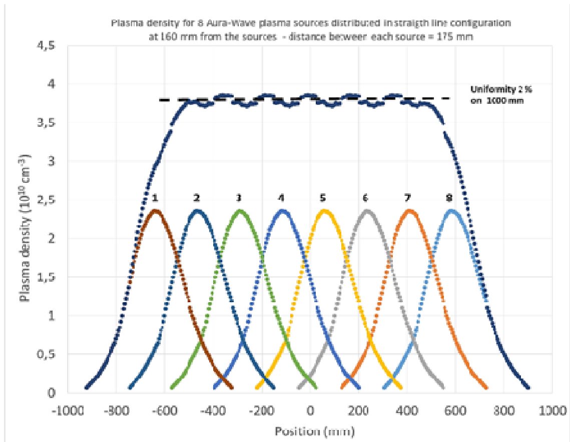


Figure 6: Theoretical distribution of 8 Aura-wave sources aligned horizontally

The influence zone of each source depends naturally on the step size chosen. In this example where the first source is positioned at the furthest extremity (*635* mm from the center), its influence is limited to the 4th source (positioned at 110 mm from the center) where each density profile overlapped. We may therefore expect to extend further this uniformity by adding progressively the number of source and taking into account the influence zone.

It should be noted that the source is characterized by a high diffusion rate. Measurement showed that the density profile was only halved at the height of 160 mm compared to the one at 85 mm.

4. Conclusion

Measurement were focused on *Aura-wave* where we managed to achieve a highly uniform plasma over a large area. Similar results were obtained with *Hi-wave* and the sources comparison will be presented during the conference. The comparison will be based on emission line intensity, plasma electronic density and plasma uniformity as a function of sources number and sources position.

5. References

[1] A. Lacoste, T. Lagarde, S. Béchu, Y. Arnal and J. Pelletier, *Plasma Sources Science and Technology*, vol. 11, pp. 407-412, 2002

[2] L. Latrasse, M. Radoiu and B. Depagneux, IMPI 48, *Microwave Power Symposium*, New Orleans, Louisiana, USA, June 2014

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