LARGE DIAMETER MICROWAVE PLASMA FOR SURFACE TREATMENT

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We have designed a large diameter (120 mm) microwave (2.45 GHz) plasma reactor for large size substrate (4 in). Argon and oxygen gases have been firstly used, at low pressure, for a better understanding of plasma behaviour in such structure. Various diagnostics have been set-up in this reactor :

- *optical measurements on different axis*
- *probe devices for local measurements*
- *mass spectrometer*

Introduction :

Within the framework of our microwave (2.45 GHz) plasma studies, we have focused our works on large diameter plasma reactors for the treatment of large area substrate (around 4 in). Our discharge is sustained by travelling surface waves. The wave power is transferred to the gas via an excitator based on the surfaguide principle.
A previous study in a two meters long plasma column has showed that in such large stucture several plasma modes are able to propagate. This result is obtained by solving the dispersion equation with an analytical method. This equation applied to our three surronding structures (plasma-quartz-air) gives a system of eight equations with eight unknows. The solutions of these equations, applied to our structure and at a frequency of 2.45 GHz, lead to phase curves of guide and plasma modes (Fig. 1). With these curves we can deduce several results :

- firstly, guide modes cannot propagate at a density higher than $n_e = 10^{11}$ cm^{-3}.
- secondly, plasma modes can propagate only if the electron density is higher than $n_{ec} \approx 3\ 10^{11}$ cm^{-3}. Above this critical density, the attenuation factor, α, becomes lower than the propagation factor β.
- thirdly, above 3.5 10^{11} cm^{-3}, only five modes can propagate in our structure. Further they have the same attenuation factors α. E. Bluem has shown that the plasma propagation is mainly due to the hexapolar mode TM^*_{30}. In this structure, he found an average electron density of 10^{12} cm^{-3} at 1 Torr, 600 W in argon gas.

Despite azimuthal and longitudinal modulations E. Bluem found that the ground atomic oxygen state obtained from actinometry method is quite homogeneous in the three directions [1].This allows us to think of this reactor as a good tool for large surface treatment.

Experimental set-up and diagnostics :

In such a large diameter reactor the plasma is enclosed in a quartz tube surrounded by a metallic tube of internal diameters of 120 and 188 mm respectively. This plasma creation zone of 0.5 m long is set up above the reactor's core (Fig. 2). The reactor's core is a diffusion area which consists of a cylinder whose dimensions are 0.5 m diameter and 0.5 m height. At the top, a short circuit limits the micro-wave propagation and thus the plasma length.

Experiments have been performed in argon and oxygen gases at low pressure (0.1 to 5 Torr) with 50 to 500 sccm of flow rate for power ranging from 200 W to 2 kW.

Emission intensities of argon and atomic oxygen lines are meaured along in two different axis (Fig. 2) :

- longitudinally (z)
- azimuthally (φ)

These optical measurements are averaged, over the plasma diameter, for z and φ.

All optic diagnostics have been done with a CCD device coupled to a 270 mm focal long spectrometer.

To estimate the local plasma homogeneity we need a more spatially resolved measurement. Thus we have designed single Langmuir probe device which consists of a tungsten wire of 100 μm diameter, and thin alumine tube as electric insulator.

The use of single probe is more difficult than double probes device, because the probe tip acts as an antenna and may collect H.F.current.

By using a passive filter, we have cut off H.F. interference. Reactor's walls have been linked to the ground and used as electric reference. Accordingly, we have a nearly constant floating potential which is the proof of a low disturbed probe measurement [2]. All the more this last result has been obtained near the quartz wall (7 mm), where the electromagnetic field reaches its highest value [4].

To get the electron temperature (Te) and the ion density (Ni) we have used the OML theory from Langmuir [3] because the ratio of the probe radius to the Debye length ($rp/\lambda d$) is less than 3.

We have developped a software wich is able to give an accurate value of Te and Ni by fitting the ionic saturation region and the exponential current region by a single curve (Fig 3). We have taken into account of the ionic saturation current in the positive potential region. This modification gives an accurate value of Te via the true slope of the exponential current region. For Ni, the good fitting between theorical calculations and experimental results (from -30 V to -5 V) leads us to think that this value is also quite accurate (Fig.3), all the more we have checked that no ionic collisions occur in the sheath [5].

We have also set up a mass spectrometer's sampling hole in the diffusion area to get qualitative knowledge of the plasma chemistry.

Results

Light intensity measurements :

Longitudinally, in argon/oxygen mixture, we have found similar modulations than those found in the two meters long structure (Fig 4). Such modulations, already observed in the E. Bluem's work, could be explained by a beat between the plasma modes. In smaller tube where a single plasma mode is present (TM_{00}), the light intensity shows a linear decrease from the surfaguide to the end of the plasma. In our structure, at lower power, modulations are surimposed on the decrease. At higher power, we see the effect of the short circuit which creates reflexions of the wave (Fig 4).

Azimuthal measurements have been done under the same conditions (Fig 5). The results obtained for 1200 W and 700 W, show that the TM^*_{30} is the main plasma propagation mode in our structure. At lower power (400 W) the wave penetration is not homogeneous and the coupling is worse.

Probe measurements :

We have calculated Ni and Te for various angular (φ) and radial (r) locations inside the discharge (Fig. 6) at a power of 400 W. All the probe characteristics have the same slope in the exponential region. So we have found the same electron temperature (Te) for two radial locations (7 and 25 mm from the quartz wall) and for all angular locations. This can be explained by the spatial diffusion of the species which leads to the homogeneization of the electrons energy.

The ionic density is also quite homogeneous: 10^{12} to 2 10^{12} cm^{-3} in the middle of the discharge and 0.5 10^{12} to 1.7 10^{12} cm^{-3} near the quartz wall (Fig 7). These results show that the radial shape of the density is quite homogeneous. Further results will be presented on the poster at higher power.

Conclusion :

Actinometry method, with the lines 777.7 nm and 750.4 nm for oxygen and argon respectively, has been applied for the longitudinal and azimuthal measurements.

Despite important longitudinal modulations of the light intensity at high power (1200W), the longitudinal distribution of the ground state atomic oxygen is quite homogeneous from the short circuit to the diffusion area.

The results obtained from the azimuthal measurements show that we have an homogeneous distribution of atomic oxygen. This is explained by the efficient diffusion of the species in this low pressure plasma. Thus with an homogeneous distribution of atomic oxygen and high energy particle ($Te \approx 2$ eV), we may use such discharge for SIO_2 deposition or surface treatment.

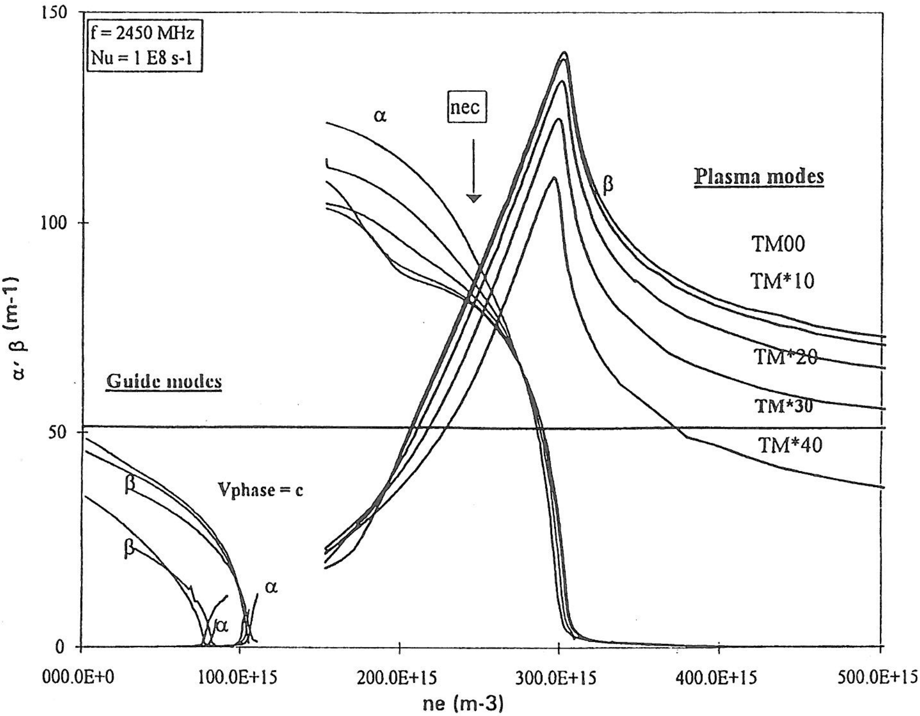

Fig n° 1 : Phase curves of propagation modes, guide and plasma, in the 120-125-188 structure. f = 2450 Mhz, $\nu = 10^8\ s^{-1}$

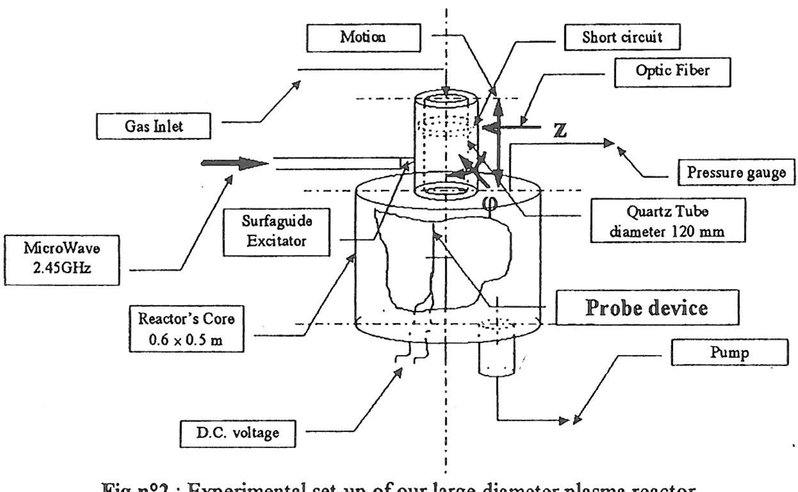

Fig n°2 : Experimental set-up of our large diameter plasma reactor

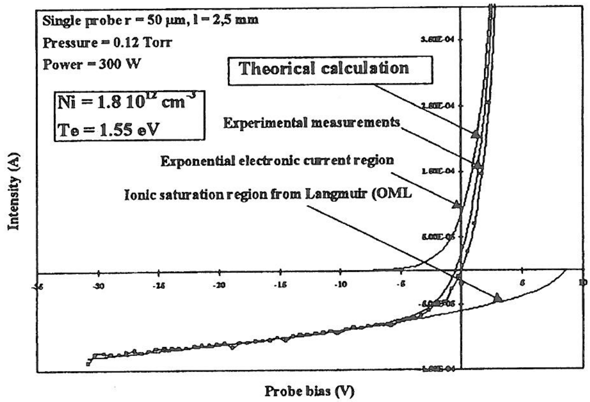

Fig n°3 : Single probe measurements and theorical fit (OML), location of the probe : 10 cm below the surfaguide and 7 mm from the quartz wall

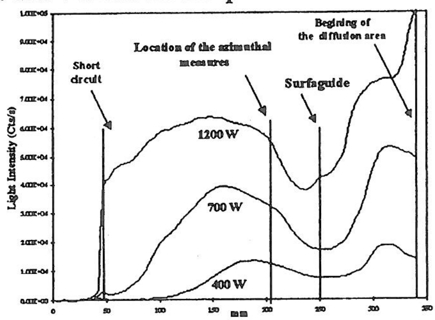

Fig n° 4 : Longitudinal evolution of the emission line of oxygen (777.7 nm). Argon/Oxygen mixture flow rate, pressure are respectively fixed at 1/49 sccm and 0.12 Torr

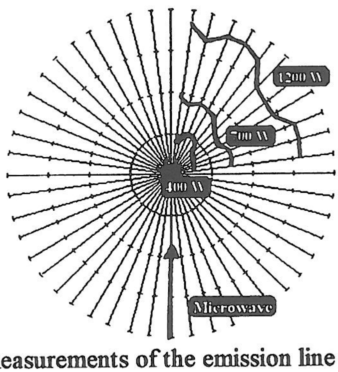

Fig n°5 : Azimuthal measurements of the emission line of Oxygen (777.7 nm). Argon/Oxygen mixture flow rate, pressure are respectively fixed at 1/49 Sccm and 0.12 Torr

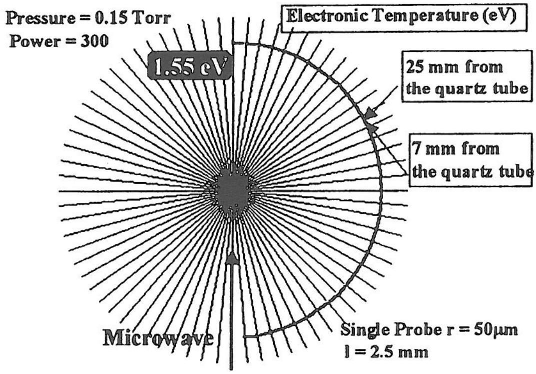

Fig n°6 : Angular variation (φ) of the electronique temperature for to differents radial locations : 25 and 7 mm from the quartz wall.

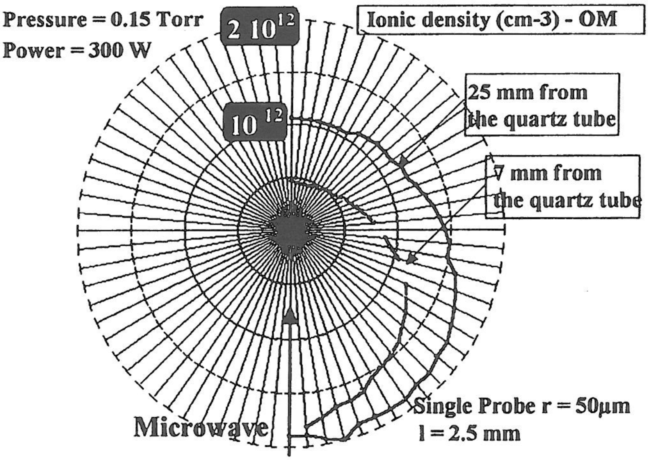

Fig n°7 : Angular variation (φ) of the electronique density for to differents radial locations : 25 and 7 mm from the quartz wall.

References :

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[5] **I. D. Sudit, R. C. Woods** 'A study of the accuracy of various Langmuir probe theories' J. Appl. Phys. 76 (8), (1994) 4488-4498