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CHARACTERIZATION OF A TUBULAR PLASMA REACTOR WITH EXTERNAL ANNULAR ELECTRODES

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Abstract. Aspects regarding the space distribution of nitrogen plasma generated by a capacitively coupled radiofrequency (13.56 MHz) discharge in a tubular glass reactor with annular external electrodes are presented. The spectra behavior along the radial direction of the reactor is studied for various applied power values.

Keywords: RF nitrogen plasma, external electrodes, spectral investigation

1. INTRODUCTION

A number of classical electrode configurations for radiofrequency discharges are noticed in the literature [1]. Even the configurations with internal electrodes were more intensively studied [2], for some classes of applications the discharges with external electrodes are more useful, as example for the better plasma purity and control of substrate bias. In spite of its classical character the radiofrequency discharge with external annular electrodes is still widely used by many research groups, especially of chemists and biologists, to activate surfaces and deposit (mainly polymeric) thin films. The treatment of polymers and the deposition of polymeric films are very sensitive processes in respect to plasma parameters, and it is not surprisingly to miss the deposition or to obtain powders if the substrate is not placed in the right position in the reactor. Consequently, beside the fundamental aspects related to the operation of such discharges, there is an important demand for characterization of deposition systems using tubular reactors with external annular electrodes. In the present work a plasma configuration with annular external electrodes is investigated by means of Optical Emission Spectroscopy.

2. EXPERIMENTAL SET-UP

The experimental set-up used for plasma investigations is presented in figure 1. The plasma reactor is a cylindrical glass tube, about 8 cm external diameter, 7.4

cm internal diameter and 50 cm long on which two metallic electrodes, parallel one to each other at 2.5 cm distance, are mounted as active RF and grounded electrodes, respectively.

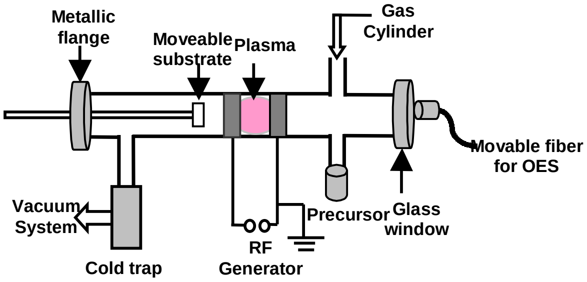

Fig. 1

Experimental set - up

The plasma was generated in flowing nitrogen by applying a radiofrequency voltage (13.56 MHz) between the annular electrodes. The glass tube is provided with a metallic flange at one end and with a transparent window at the other end. The metallic flange allows to introduce the gas (nitrogen) in the discharge and to pump the system with a rotary mechanical pump. The plasma emission was collected with a typical Optical Emission Spectroscopy system consisting of optical fiber, monochromator, photomultiplier, amplifier, and acquisition system. The fiber end is moveable along the radial and axial directions of the reactor, integrating the axial and respectively radial plasma emission with a space resolution of 3.5 mm.

3. RESULTS AND DISCUSSION

As we can see in the Figure 2, the plasma is more intense in the vicinity of the walls than in the reactor centre, but also its color is changing along the radius. The two violet rings correspond to the electrodes position. The emission characteristics were recorded in the 210-620 nm spectral region. In all the investigated positions, along the radial and axial direction of the reactor, the spectra exhibit the emission of the nitrogen molecular bands [3] of the Second Positive System (SPS) N_2 ($C^3\Pi_u$ – $B^3\Pi_g$) and First Positive System (FPS) N_2 ($B^3\Pi$ - $A^3\Sigma$). In figure 3 are presented two spectra, recorded in the vicinity of the reactor wall and in the center, respectively. They show different overall intensities and distributions of the nitrogen spectral systems. The peaks corresponding to SPS (0-0) transition at 3371.3 Å, and FPS (8,4) transition at 5959 Å were chosen to characterize the space plasma distribution along the radial and axial directions.

Fig. 2

Radial plasma view

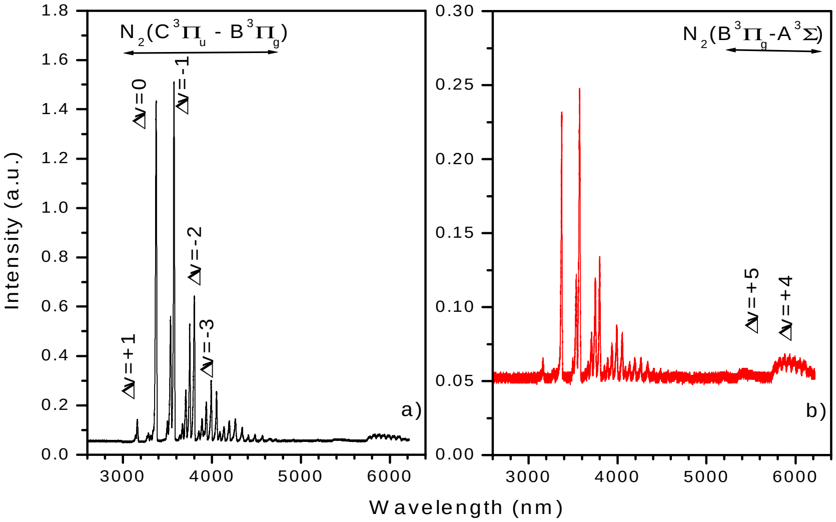

Fig. 3

Spectra recorded in the vicinity of the reactor wall (a) and in the reactor center (b)

The variation of the intensities of FPS (8,4) and SPS (0,0) transitions in the radial direction, for 60 W, are presented in Figure 4a) and b), respectively. Only a slight dependence on the radius is observed around the tube centre, pointing out to the existence of a homogenous plasma region. Contrary, in the proximity of the tube walls, strong dependencies on radius are noticed, which are related to the presence of plasma sheaths, developed in the electrodes vicinities. Similar dependencies are obtained for all powers in the range 40-200 W.

In a very crude approximation (equilibrium, excitation based on electronic collisions, neglecting of radiative cascade) the intensity ratio I_{SPS}/I_{FPS} can be used to illustrate the space distribution of the electronic temperature in the investigated space, considering that higher is this ratio, higher is the electrons temperature.

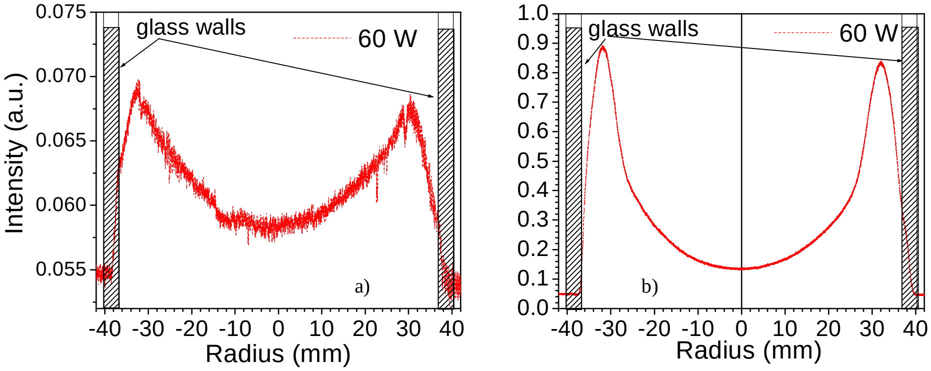

Fig. 4.

Intensity of a) FPS (595,9 nm) line and b) SPS (337,1 nm) line along the radial direction of investigation for RF power = 60 W

The dependence of this ratio upon radius, for 60 W RF applied power, is presented in Figure 5a. It points out to a higher electron temperature in the electrodes vicinity, result which is explained by the electrons acceleration in the plasma sheath. The dependence of this intensity ratio, for the tube centre and for the maximums region, upon power is presented in Figure 5b.

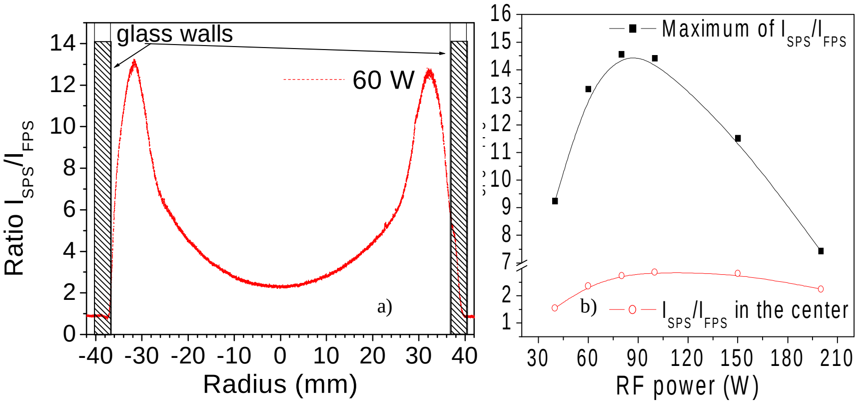

Fig. 5

a) I_{SPS}/I_{FPS} ratio along the radial direction of investigation for RF power = 60 W; b) Values of I_{SPS}/I_{FPS} ratio corresponding to the center (-■-) and to the maximum (-○-) as function of RF power

The curves indicate that, up to a given value, the power increase causes the temperature increase, with a high rate in the sheath region and with a moderate rate in the homogeneous plasma central region. After this power value the temperature tends to decrease.

The dependence upon power of the position of maximum of the ratio I_{SPS}/I_{FPS} with respect to the tube wall was studied as well. In Figure 6 it can be noticed its displacement toward the reactor walls as the RF power increase. Since the sheath thickness is a decreasing function of the discharge power [4], the displacement of the maximum is related to the modification of the plasma sheath dimension.

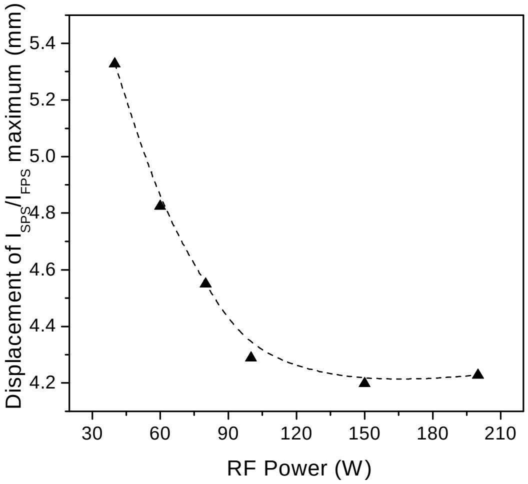

Fig. 6

Position of the maximum of I_{SPS}/I_{FPS} in respect to the reactor walls as function of RF power

4. CONCLUSION

The space distribution of spectral emission and of electron temperatures in the tubular reactor with external anullar electrodes is strongly dependent on position. Marked inhomogeneities are observed in the electrodes proximity, where plasma sheaths are present, while a quite homogeneous zone which might be useful for deposition is identified in the reactor centre.

Acknowledgements

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