Influence of the gas flow rate on the column length and the electron density in an argon surface wave sustained discharge at atmospheric pressure

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In this work, we have studied the influence of the gas flow rate on the column length and the electron density in an argon surface wave sustained discharge at atmospheric pressure. The wave launcher employed was a surfaguide operating at 2.45 GHz. The discharge was sustained in a quartz tube of 1.5 and 4 mm inner and outer diameter, respectively. The applied microwave power was varied between 70 and 300 W for two different gas flow rates: 0.25 and 1.00 slm and light emitted by the discharge was analyzed using a 1 m focal length Czerny-Turner monochromator. The results obtained can be useful for optimizing the argon plasma as excitation source in chemical analysis.

1. Introduction

The excitation of samples for chemical analysis by plasmas is influenced by the residence time of the sample in the discharge. The high pressure regime is the most appropriate for the analytical chemistry because it is hardly collisional and facilitates the sample excitation. Surface wave sustained discharges at atmospheric pressure presents a length proportional to the absorbed microwave power [1], it allows optimizing the contact time of the sample with the discharge.

Previous works show the influence of the operative frequency, gas pressure and tube radius on the plasma length [2]. The influence of the gas flow on the electron density and on column length in surface wave sustained discharges have been studied by Daviaud [3] and Czylkowsky *et al.* [4], respectively.

In this work we analyze two Ar plasma columns sustained by surface waves at atmospheric pressure. To create both plasma columns a surfaguide was used. This device launches a surface waves along the discharge tube in two way directions, creating and sustaining a plasma column that extended to both sides of it: the direct and inverse column. The direct column is characterized by the fact that the surface wave propagation and the gas flow are in the same direction, whereas in the inverse column the wave propagation and the flow are in the opposite direction. We have obtained experimentally the influence of the gas flow on the length and on the axial profile of the electron density for each column.

We have measured the length and the electron density axial profile of both the direct and inverse columns as a function of microwave absorbed power for different gas flow rates. The electron density of both columns has been determined by optical emission spectroscopy. Our results agree with those obtained by Daviaud [3] and Czylkowsky *et al.* [4].

2. Experimental set-up

The plasma source and the diagnostic tools are shown schematically in figure 1. The discharge is sustained in Ar by an azimuthally symmetric electromagnetic surface wave excited by a surfaguide [5] wave-launcher at 2.45 GHz. The incident power (P_I) varied between 70 and 300 W and the reflected power (P_R) was less than 5% of P_I. The discharge tube was made of quartz with an inner diameter of 1.5 mm. This diameter prevents the radial contraction of the discharge and avoids discharge splitting up in filaments [6-7]. Light emitted from the plasma was collected by an optical fibre connected to the entrance slit of a 1 m focal length monochromator, equipped with a 2400 grooves/mm holographic grating.

The argon gas flows used were 0.25 and 1.00 slm from the bottom to the top.

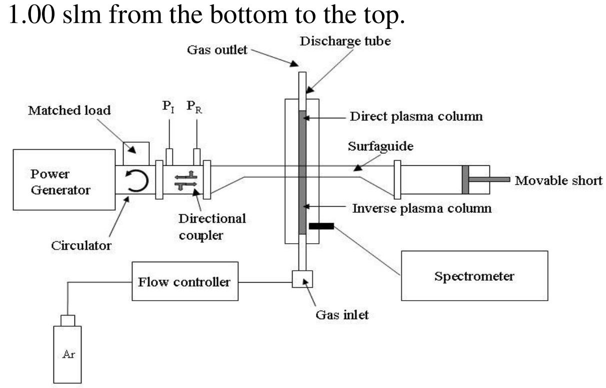

Fig. 1 Experimental set-up

3. Diagnostic methods

a) Plasma column length

Lengths of the direct and inverse columns were measured as a function of the absorbed microwave power $P_{abs} = P_I - P_R$, for two gas flows rates. The total length of the plasma column is the sum of both lengths including the plasma part in the surfaguide gap.

b) Electron density

Electron density in the microwave discharge was determined from the Stark broadening of the H_β line (486.13 nm). The hydrogen atoms appear in the discharge as impurities.

The collisional broadening of the Balmer lines is dominated by the linear Stark effect. Kepple and Griem [8] have calculated that the relationship between the electron density and the Stark full width at half maximum of these lines is given by the expression:

$$\Delta\lambda_s = 2.5\ 10^{-19}\ \alpha_{1/2}(H_\beta)\ n_e^{2/3} \qquad (1)$$

where n_e is the electron density expressed in cm^{-3} and the parameter $\alpha_{1/2}(H_\beta)$ is the fractional semi-half-width. This parameter is tabulated in [9] and depends on the Balmer line used and on the electron temperature. The Kepple Griem theory doesn't include the ion dynamics to evaluate the theoretical profile of the Balmer lines. Influence of this effect can be neglected in the case of the H_β line when the electron density is equal or higher than 10^{14} cm^{-3} [10].

4. Results and discussions

a) Plasma column length

Figure 2 shows the variation of the total plasma column length as a function of the microwave power absorbed by the discharge for two gas flow rates: 0.25 slm and 1.00 slm. The plasma column length increases as absorbed microwave power increases as expected in surface wave sustained discharges. The total plasma column length is independent of the gas flow and shows a quasi-linear variation as in Ne discharges [2,11]. This trend seems characteristic of surface wave sustained discharges at atmospheric pressure.

Figures 3 and 4 show the direct and inverse plasma column lengths as a function of the microwave absorbed power, for Ar gas flows of 0.25 and 1.00 slm, respectively. These figures clearly show that at atmospheric pressure the inverse column length is smaller than the direct column length. For a gas flow rate of 0.25 slm, the inverse column length decreases 20 % respect to the direct column length and for a gas flow rate of 1.00 slm the decrease of the inverse plasma column length is 40%. Then the difference between both lengths increases when the gas flow rate increases. Finally, we can conclude that the gas flow sense and velocity affect the column length of the plasma.

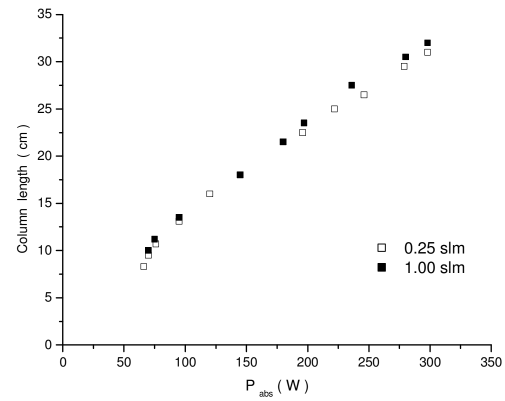

Fig.2 Column length as function of the absorbed power

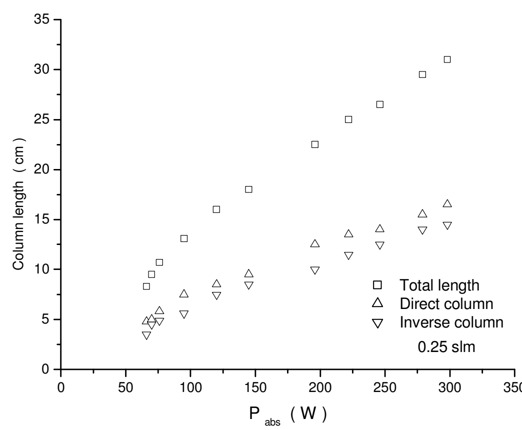

Fig. 3 Lengths of direct and inverse columns, flow 0.25 slm

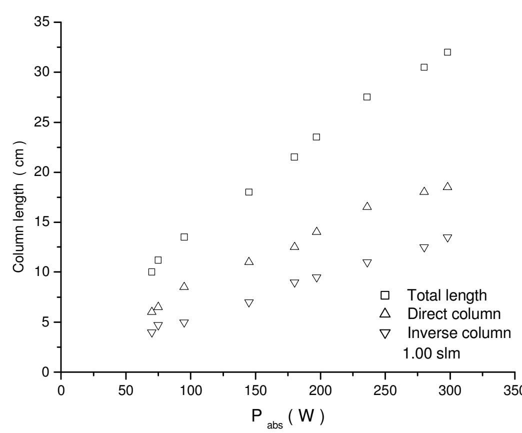

Fig. 4 Lengths of direct and inverse columns, flow 1.00 slm

This difference between the lengths of the direct and inverse columns agrees with the results obtained by Czylkowsky *et al*. [4]. These authors show that the difference between the direct and inverse column lengths decreases with increasing the gas tube diameter at the same gas flow. In this case the gas flow velocity trough the discharge tube diminishes and its influence on the column length is less important.

b)Electron density

Figure 5 presents n_e measured as a function of axial position in the direct and inverse columns for 0.25 and 1.00 slm flows. For both cases, the electron density increases linearly from the end of the plasma column (z=0) to the wave launcher which is characteristic of surface wave sustained discharges. The direct plasma column exhibits a steeper gradient of the electron density axial profile than in the inverse plasma column. By increasing the gas flow rate the differences between the slopes of the direct and inverse columns become more important.

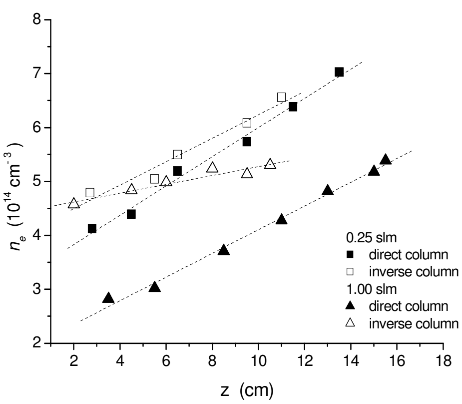

Fig. 5 Axial variation of the electron density

A similar result is the one obtained by Daviaud [3] in a He surface wave sustained discharge at reduced pressure. At reduced pressure the axial electron density profiles of the direct and inverse columns also depend on the flow sense. In the direct column the electron density axial gradient increases rapidly from the end of the column to the gap whereas in the inverse column the slope of the electron density axial profile is smaller.

We can conclude that when the gas flow increases the inverse column length decreases and the slop of n_e axial variation is lower than in the case of the direct column.

5. References

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