H_α and H_β Line Broadenings in Microplasma Jets at Atmospheric Pressure

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***Abstract* — Microplasma jets of argon/hydrogen mixture were generated by radio-frequency waves at 144 MHz with powers ranging from 5W to 50W with length up to 30.0 mm. Broadening mechanisms of H_α and H_β lines were studied. The most important one in the H_β line is due to Stark effect. Through the analysis of H_β line, the electron density was measured as a function of power and position in the jet. The broadening of H_α line may be mainly due to the Doppler effect, enabling to determine hydrogen atom temperature which was found to be 23000 K in the argon/hydrogen microplasma jet.**

***Keywords* — RF Microplasma Jets, Plasmas at Atmospheric Pressure, Broadening of Balmer Lines, Electronic Density, Rotational Temperature, Atomic Temperature.**

I. INTRODUCTION

Microdischarge studies at atmospheric pressure are a subject of intense research in the last few years due to many industrial applications being a cheaper alternative in relation to low-pressure plasma systems. Microplasmas are being considered in several and different fields such as material processing [1], gas treatment [2] and analytical chemistry [3].

Microplasmas may be generated at atmospheric pressure by applying an external DC voltage between electrodes [4]. However, microdischarges could be excited by radio-frequency waves (RF) as well [1,2,3,5,6]. The main advantage of RF related to DC techniques is the fact that the RF microplasmas yielded do not contain impurities from electrodes.

In this work, electric and spectroscopic properties of the argon/hydrogen mixture microplasma are analyzed.

II. EXPERIMENTAL SETUP

An RF generator ICOM IC-V8000 at 144 MHz was used to excite a coaxial structure made by an outer metallic block with a hole diameter of 3.3mm and another metallic tube with a diameter of about 1.0mm. These metals are separated by a ceramic tube whose the inner diameter is 2.2mm (Figure 1). Incident RF power of 5W, 9W, 20W and 50W were employed in this work. To obtain the best energy coupling from the generator to the microplasma an L-type matching network was used (Figure 2).

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The gas flow used in the experiments was a mixture of 98%Ar – 2% H_2 at 700sccm (Figure 1). The incident and reflected power were monitored by a wattmeter Cellwave KW-525. The peak-to-peak voltage at the generator exit as well as at the electrodes of the L-type filter were measured with an oscilloscope HP-54502A. To infer the impedance of the filter componentes (coil and capacitors) a network analyzer HP-8714C was used.

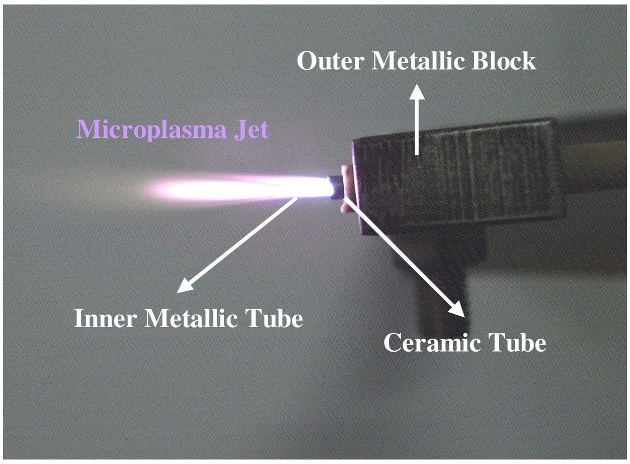

Fig.1. A picture of the coaxial structure with the microplasma jet of Ar/H_2 yielded by 50W at 700sccm gas flow. In this case, the microplasma jet length is about 30.0 mm.

The next step was to realize a spectroscopic study of the radiation emitted by the Ar/H_2 microplasma. The emission spectra of Ar/H_2 mixture in the 3000Å to 9000Å range were recorded in order to identify the emission lines and bands. Particularly it was studied the molecular band of the OH by using a high resolution spectrometer. The gas temperature was estimated from the OH rotational bands that are very intense in the optical spectrum. The OH is formed by electron dissociation of water vapor present in the mixture. The OH (A $^2\Sigma^+$,v=0 $\rightarrow$ X $^2\Pi$,v=0) band system is formed through excitation of OH by electronic impact.

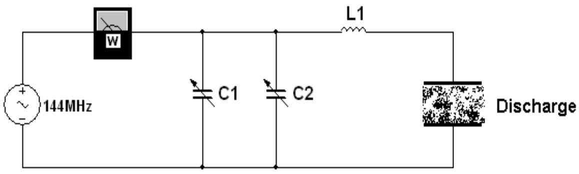

Fig.2. Schematic sketch of the electric circuit used in the experiments.

III. RESULTS

The electrical properties of the microplasma jet were determined as a function of RF-powers. In each case the peak-to-peak voltage at the power source were measured, as well as the correspondent peak-to-peak voltage at the exit of the L-type filter during the microplasma jet formation (Table I). Moreover, it was also possible to measure the maximum power transferred from the generator to the load, i.e. the plasma jet (Table I). As can be seen the peak-to-peak voltages increase as long as the RF power increases too. The estimated phase shift between the generator and the microplasma voltages is 80.5°.

We also observed that the length of microplasma jet changes for each power applied (e.g., 6.0 mm at 5W and 15.0 mm at 50W).

TABLE I. Powers (P_G) and peak-to-peak voltages (V_G) of the generator as well as powers (P_F) and peak-to-peak voltages (V_F) of L-type filter are shown.

P_G (W)	P_F(W)	V_G (V_{pp})	V_F (V_{pp})
5.0 ± 0.1	4.4 ± 0.1	47.5 ± 25	124.7± 2.5
9.0 ± 0.5	7.7 ± 0.5	62.5 ± 2.5	163.5 ± 2.5
20.0 ± 0.5	15.2 ± 0.5	91.3 ± 2.5	239.9 ± 2.5
50.0 ± 5.0	40.1 ± 5.0	139.1 ± 2.5	365.4 ± 2.5

By simple analysis of the circuit (Figure 2), we have calculated the impedance of the microplasma jet (Z_P) to be:

$$Z_P = 380\Omega - j\,960\Omega \qquad (1)$$

It was verified that this value does not change so much when power is varied.

Finally, spectra of the Ar/H_2 mixture of the microplasma jet were recorded in the region 3060Å–3150Å (Figure 3), in order to determine the rotational temperature of the OH transition (A $^2\Sigma^+$, v=0 → X $^2\Pi$, v=0). A typical value of the rotational temperature is (750 ± 50) K for a microplasma jet working with power of 50W.

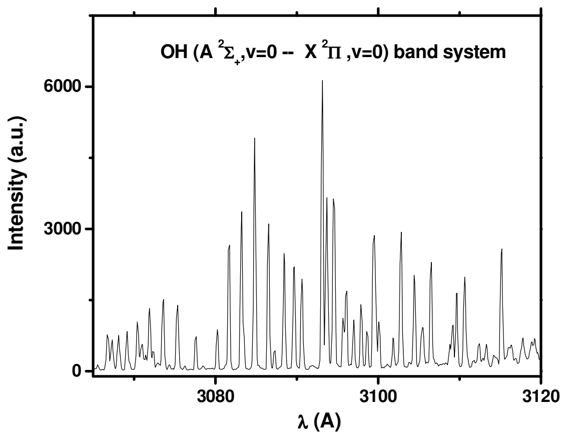

Fig. 3. Emission spectrum of OH band.

Temperature measurements were done along the plasma as a function of RF-powers. These are important parameters for evaluation of Doppler broadening of H_α and H_β lines. The main mechanisms responsible for broadening of H_α and H_β lines are instrumental, natural, Doppler, Stark, resonance and van der Waals [7]. Among these effects, resonance and natural ones are not important in the present experimental conditions. In order to evaluate the importance of each process in the H_α and H_β lineshapes, a careful analysis was undertaken as a function of electron density and temperature. The Figure 4 is a typical example of this analysis when electron density is varied and the electron and gas temperature is held constant.

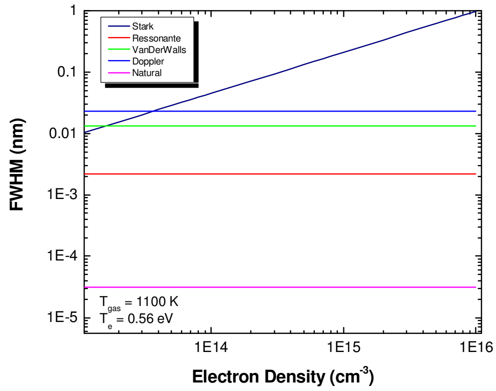

Fig. 4. The H_β line broadening as a function of the electron density (LTE) at atmospheric pressure.

As can be seen, the most important line broadening mechanisms are the Stark and Doppler ones. The Figure 5 shows a typical H_β line profile recorded in the jet. It can be seen the Voigt profile (red line) that fits the experimental points (■). In this case, the Voigt simulated profile is the result of a convolution of apparatus function, Doppler (Gaussian profile $\Delta\lambda$=0.213 nm) and the broadening by Stark effect (lorentizan profile) due to charges present in the plasma.

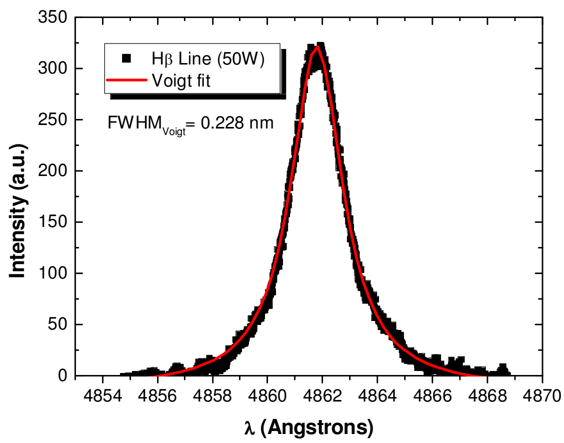

Fig. 5. Emission profile of H_β line.

The Full Width Half Maximum (FWHM) of the lorentizan line is related to the electron density by the relation [8]:

$$n_e = 1.09 \times 10^{16}\,[\mathrm{FWHM}(H\beta)]^{1.458}\ \mathrm{cm}^{-3} \qquad (2)$$

By using this relation the electron density was measured as a function of power and position in the jet as can be seen in Figure 6.

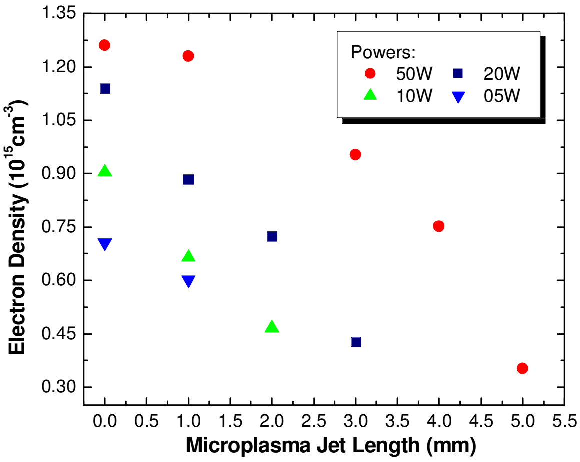

Fig. 6. Electron density as a function of power and position in the jet.

Through the analysis of the main broadening mechanisms in the H_α line, it can be shown that Doppler, Stark, van der Waals and instrumental are the most important as can be seen in the Figure 7 [7].

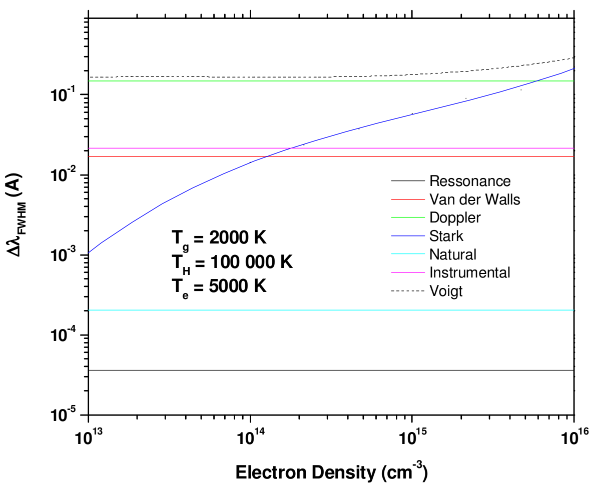

Fig. 7. The H_α line broadening as a function of the electron density (LTE) at atmospheric pressure.

By recording profiles of the H_α line as a function of power and position along the jet and taking into account the broadening mechanisms of this line, the temperature of hydrogen atom could be determined. Correct accounting of the fine structure of H_α line is imperative in the determination of hydrogen atom temperature. A study of the fine structure contribution to the H_α line was done in order to evaluate the correct atomic temperature. The Figure 8 shows a typical example of a multiplet structure contribution of the whole profile.

These are the first results of our analysis. Hot atoms were measured, e.g. the temperature at jet nozzle is (23000 ± 1000) K. The work is in progress in order to evaluate the hydrogen atom temperature along the jet.

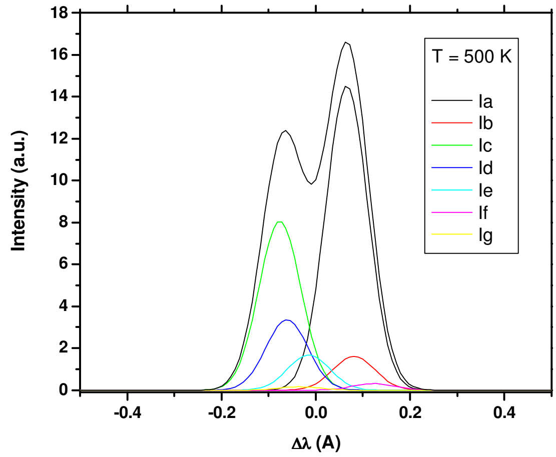

Fig.8. Synthetic H_α line generated as a sum of 7 Gaussians (T=500 K). $I_a - I_f$ are emissions due to the fine structure components of the line.

IV. CONCLUSIONS

By using a radio-frequency power source at 144.0 MHz it was possible to create long microplasma jets at atmospheric pressure. The power losses through the system were not so significant indicating that the L-type matching network is useful to match these impedances, i.e. impedance of the generator and the microplasma jet. The microplasma impedance indicates that this load has a capacitive nature. Rotational temperature from OH transition (A $^2\Sigma^+$,v=0 → X $^2\Pi$,v=0) was determined and found to be (750 ± 50) K for a microplasma jet working with power of 50W and may reach values of (3000 ± 200) K along the jet.

In order to evaluate the importance of each process in the lineshape broadening of the H_α and H_β lines a careful analysis was undertaken as a function of electron density and temperature. Electron density was measured as a function of power and position in the jet (found in the range of 3.5 x 10^{14} cm^{-3} up to 1.3 x 10^{15} cm^{-3}).

By recording profiles of H_α line and by taking into account the broadening mechanisms and the fine structure of the line, the temperature of hydrogen atom could be determined to be (23000 ± 1000) K at jet nozzle.

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