A spectral study of a single-electrode filamentary plasma jet in Argon and Argon-Nitrogen

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The present work describes a plasma jet generated at atmospheric pressure using argon or argon/nitrogen mixtures. The spectral properties of this plasma jet have been studied comparatively. Species were identified and tracked along the jet axis and rotational temperatures using the OH radical emission were extracted proving the cold character of both plasmas.

1. Introduction

The importance of atmospheric pressure plasma sources generating long and cold plasma jets is well known and studied in recent years.

In this work we present a spectral study of a radiofrequency generated long plasma jet working with a single active electrode in open atmosphere. The discharge uses argon or an argon/nitrogen mixture.

We were interested to observe the influence of nitrogen on the operation and spectral properties of the argon plasma jet. We have investigated the two jets by means of OES (Optical Emission Spectroscopy) and analyzed the plasma species and gas temperatures (as determined from simulations of the OH radical emission). The comparison of these two plasmas showed that inserting just a small amount of nitrogen (~1%) into the discharge has a great influence on the general aspect of the plasma jet, plasma species and the gas temperatures.

2. Experimental

The experimental setup comprises the plasma source and associated optical components devoted to the spectral diagnostics. A schematic view of the setup is presented in Figure 1. The discharge is initiated inside a glass tube of 6.5mm outer diameter and 3.5mm inner diameter. An annular aluminum electrode is placed on the outside of the glass tube; this is the powered RF electrode. There is no grounded electrode in the discharge vicinity; the ground cable comes from the matching box and is disconnected before it reaches the plasma source. In other words, after the ignition, this plasma source uses a single-electrode configuration. The power to the discharge is ensured via a computer controlled AD-TEC AX-600 III radiofrequency generator (13.56MHz) and an automatic matching network.

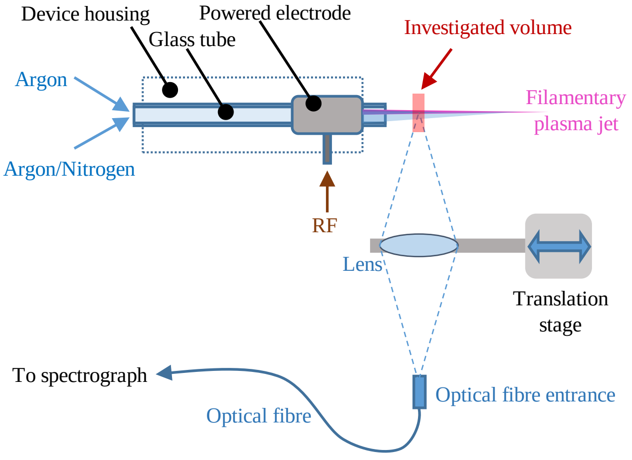

Figure 1. Schematic representation of the experimental setup showing the plasma source and the light collecting optics

The measurements were performed in open atmosphere. For the argon discharge the flow value was set to 2500sccm, while the argon-nitrogen mixture flow values were 2500sccm Ar and 30sccm N_2. The forwarded RF power values were 60W for the argon discharge and 130W for the argon/nitrogen discharge. The spectral study was conducted using a Horiba Jobin-Yvon FHR 1000 spectrograph equipped with a grating of 1200 traces per millimeter and an Andor iDus CCD camera. The optical fiber is placed in the focal plane of a quartz lens with 200mm focal length. Using this setup, the magnification factor was 1:1. This was relevant for the space-resolved measurements in order to study the presence and evolution of different plasma species along the jet axis. In order to study the plasma jets on their entire length, the lens was placed onto an X-Y translation stage which allowed for specific analysis of 4mm segments of the discharge volume. With this setup, general spectra in the domain of 200-1000nm and detailed spectra of the 306nm bands system of the OH (A-X) radical were acquired. Fitting the experimental data with simulated spectra of the OH molecule, the rotational temperature was extracted, and thus the gas temperature has been determined.

3. Results and discussion

The aspects of the two jets show major differences in that the argon discharge is of a larger length while the argon/nitrogen is somehow smaller. The argon discharge is composed mainly from a filamentary discharge coupled with a rather diffuse adjacent discharge. The argon/nitrogen discharge is completely diffuse. The general luminosity of the argon discharge is much higher compared to the argon/nitrogen one, despite being sustained at a lower RF power value. The visual differences are shown in Figure 2. The spectral analysis of the two plasmas revealed major differences in the spectral species present in the discharges. A general spectrum of the Argon plasma, recorded at 4mm from the tube exit is shown in Figure 3.

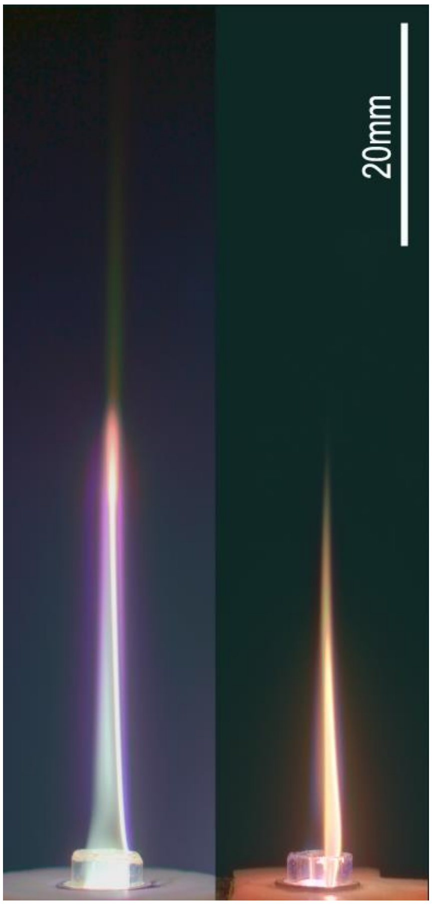

Figure 2. Photographs of the two plasma jets: *Left*-argon-only discharge (operated at 60W and 2500sccm), *Right*-argon/nitrogen discharge (operated at 130W, 2500sccm argon and 30sccm nitrogen). Images are at the same scale and were acquired using the same exposure parameters.

The spectrum is dominated by OH ($A^2\Sigma^+$- $X^2\Pi$, 308.9nm) and N_2 molecular species (Second Positive System-SPS) in the blue region and by Ar I lines in the red region. The signature of OI at 777.1nm is also present. A spectrum of the argon/nitrogen plasma recorded at 4mm from the tube exit is shown in Figure 4. This plasma jet is mostly dominated by nitrogen, with a somehow week OH spectral signature. Argon is almost completely invisible in the spectra. Using spectra acquired along the plasma jets axis with a resolution of 4mm for each step, we have determined the general evolution of some representative lines of the OH (308.9nm), N_2 (337.1nm), O I (777.1nm) and Ar I (714.7nm and 866.7nm) species.

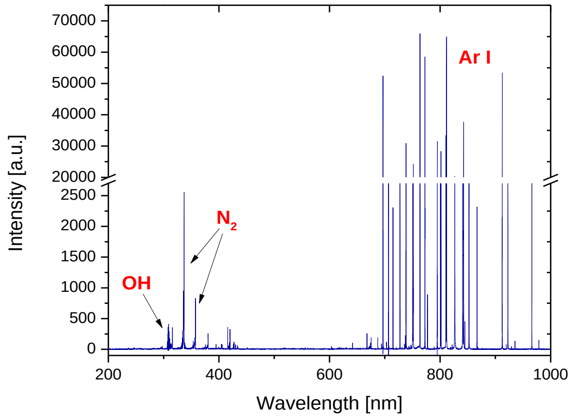

Figure 3. Spectra of the plasma obtained at 60W and 2500sccm argon. The spectrum was recorded at 4mm from the tube end.

Figure 5 shows this variation for the argon plasma jet operated at 60W and 2500sccm. An actual image of the plasma at the same scale is inserted in the plot, allowing thus a visual correlation of the line variation with the visible length of the jet.

It can be observed that the argon lines decrease in intensity closer to the tube exit compared to the molecular spectra of the OH and N_2 species and also of the atomic line of the oxygen species. This can be correlated with a mixing of the discharge gas with the surrounding air near the tip of the filamentary discharge due mostly to the evolution of the gas flow from laminar to turbulent. The post discharge observable from around 34mm away from the tube exit is mostly dominated by an oxygen/nitrogen discharge.

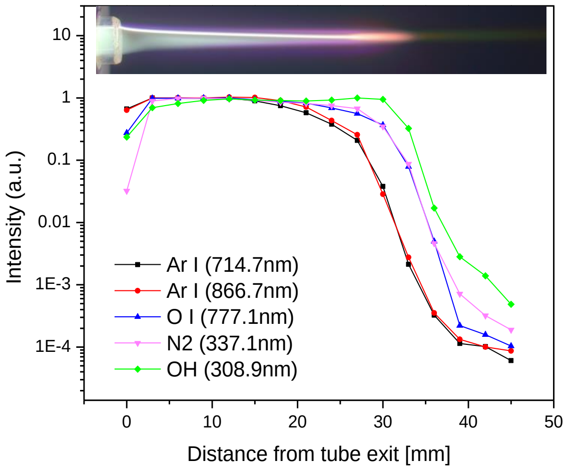

Figure 4. Evolution of the intensity of five selected lines along the argon plasma jet axis.

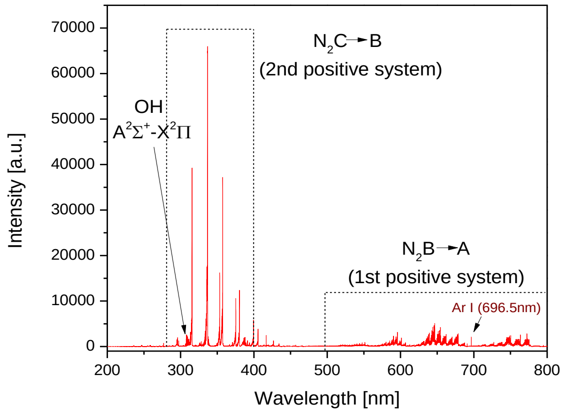

Figure 5. Spectra of the Argon/Nitrogen discharge at 130W and 2500sccm Ar and 20sccm N2. The spectra was recorded at 4mm from the tube end.

The argon/nitrogen plasma jet presents a different spectrum (Figure 5), dominated by the spectral signature of the N_2 molecule. The First Positive System (FPS) and Second Positive System (SPS) are both well represented. The only other significant species is that of the OH ($A^2\Sigma^+$- $X^2\Pi$, 308.9nm). Argon is present with only one line at 696.5nm.

A study of the evolution of the intensity for some selected lines was conducted for this discharge at 130W (Figure 6).

In contrast to the spectra of the argon discharge, the argon/nitrogen lines evolution looks linear for all of the investigated species, decreasing from the tube exit along the plasma jet.

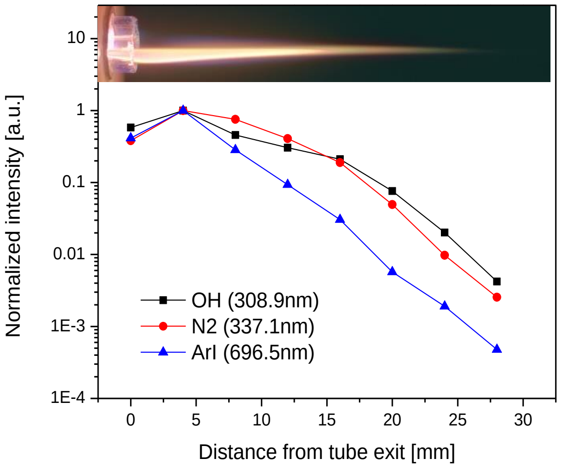

Figure 6. Evolution of the intensity of five selected lines along the argon/nitrogen plasma jet axis.

Due to the presence of the OH spectral signature, a rotational temperature determination

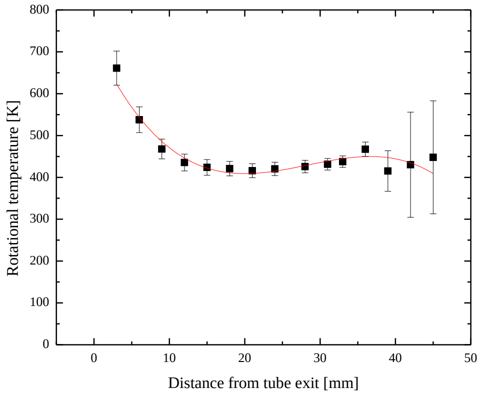

Figure 7. Rotational temperature variation along the argon plasma jet axis.

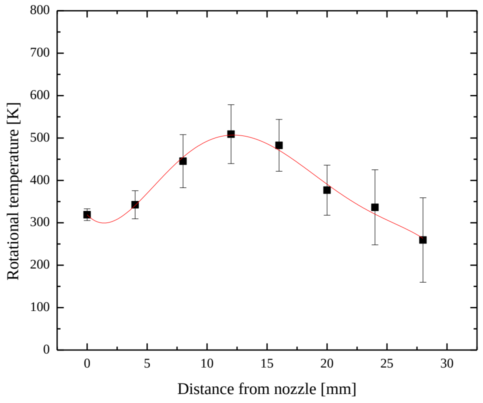

Figure 8. Rotational temperature variation along the argon/nitrogen plasma jet axis.

was possible for both argon and argon/nitrogen plasma jets.

The temperature variations, along the axis of the plasma jet, are shown in Figures 7 and 8.

The argon jet has a rather constant temperature along its axis, with a mean value of 430K. A higher value is observable near the tube exit, where the temperature reaches 600K, bur decreases rapidly. The argon/nitrogen indicates a temperature which has a maximum at around half the length of the jet, at 500K, but the values for the points near the tube exit and near the tip of the plasma jet are around 300K. Thus, the temperature of the argon/nitrogen jet is clearly lower compared to the argon discharge. This is unexpected, since normally the nitrogen plasma should have a higher gas temperature. We advance as explanation the presence of the filamentary zone in the argon plasma. We have shown previously [1] that this constricted discharge region propagates along a large distance (see Fig. 2) and is characterized by high gas and excitation temperatures (about 1eV). This allows the transport of excitation at large distances from the tube exit.

Contrary, such a filament is not observed in the argon nitrogen plasma jet, and the discharge belongs to a different, diffuse regime which is also colder.

Conclusions:

A stable radiofrequency plasma jet was generated in a single electrode configuration using argon and an argon/nitrogen mixture at atmospheric pressure.

The two different plasma jets were investigated using OES. The results revealed that, despite the low value of nitrogen concentration (~1%) in the argon discharge, the two plasma jets were very different in terms of plasma species and gas temperatures.

The argon discharge is basically composed of two plasma regions, one being the filament, the second being a diffuse plasma surrounding the filament. In comparison, the argon/nitrogen plasma jet is diffuse. Despite being fuelled by almost twice the forwarded power compared to the argon-only discharge, the temperature has a lower value, and this is mostly due to the absence of a filamentary zone. The filament also allows for energy transport to larger distances from the tube exit, enabling in argon the excitation of the plasma species along its length.

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References

[1] M. Teodorescu, M. Bazavan, E. R. Ionita, G. Dinescu, *Plasma Sources Science and Technology, (in press, 2015).*