Spatiotemporal distribution of noble gas and air species within a DBD plasma jet working at atmospheric pressure

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An asymmetric dielectric barrier discharge has been developed as ions source. This ionization source has been created with the final aim to be coupled with a mass spectrometer to allow detection of analyte deposited on a surface or injected in a gas flow. In this work the optical characterization of this source is reported. The characterization is performed with an iCCD camera and optical spectrometers.

1. Introduction

During the last decades non-thermal atmospheric pressure plasma sources have received a great deal of attention of many research groups [1-3]. Various sources with different configurations have been investigated [4]. These sources don't need expensive vacuum equipment and their properties make them a useful tool in many domains. In this work a plasma source has been developed. The final aim is to couple it, as ionization source, with a Time-Of-Flight Mass Spectrometer (TOF MS) in order to study its potential use in analytical chemistry [5; 6]. The goal is the direct introduction of the sample to be analysed into the gas stream or deposit on the plasma exposed surface.

Among the atmospheric pressure plasma sources, dielectric barrier discharges (DBD) have been [7] investigated. This kind of source generates cold plasma and creates a soft ionization which avoids the fragmentation of the analyte. The fragmentation makes difficult the identification of the molecules of interest. The source developed in our laboratory is based on DBD in such a configuration that no conductive electrode is needed inside the source. It allows the formation of a plasma jet in open air. The jet can be directed toward the surface to be analysed.

In this work an iCCD camera will be used in order to observe the spatiotemporal evolution of the jet during the positive and the negative half periods. Then optical filters coupled with the iCCD camera will be used in order to study spatial distributions of several noble gas and air species present within the jet during the positive half period.

2. Experimental setup

The experimental apparatus is shown on figure 1. It consists of a dielectric cylinder ending by a dielectric cone with a smaller diameter. Electrodes surround each part of the device. The originality of this source is its asymmetric geometry.

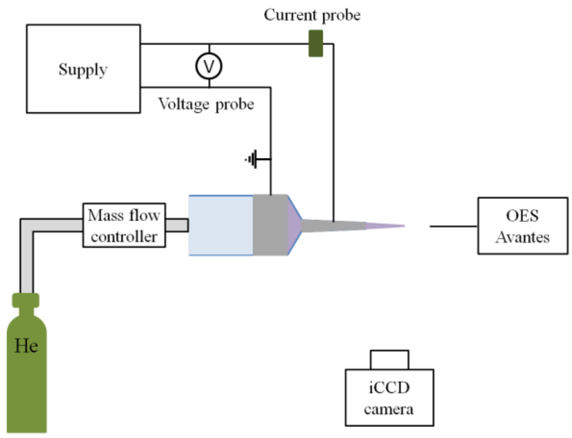

Figure 1: Experimental apparatus of the DBD plasma jet.

The source is fed with high purity Helium. It is introduced into the source through a gas inlet connected to the back of the source. A mass flow controller regulates the flow rate. It can vary from 0.1 to 21.2 $L.min^{-1}$. The source is powered with a symmetric square alternative voltage. The frequency delivered by the supply can vary from 10 to 100 kHz, and the maximum amplitude is 3 kV (6 kV peak to peak voltage) with a rising/falling time of 100 ns.

Optical measurements are performed with an optical spectrometer (Avantes 2048-2) placed in front of the source end and an iCCD camera (Princeton PIMAX-2K-RB) placed on the side of the plasma jet. Optical filters with central wavelength at 380 nm, 390 nm, 430 nm, 590 nm and 780 nm (band pass region of 10 nm for each); are used with the iCCD camera.

3. Results

3.1 Development of the discharge

We have recorded the discharge with the iCCD camera in order to study its temporal and spatial evolutions. See-through electrodes are used to observe the discharge inside the plasma source. On the figure 2 we can see pictures obtained for 24 µs exposure time: fig.2 a) the picture is taken over the positive half period and fig.2 b) over the negative half period. The discharges are different depending polarities. During the positive half period a long plasma jet extends out of the tube, whereas in negative polarity the jet is clearly shorter and has a weaker intensity. For both polarities, the plasma covers entirely the inside surface of the dielectric cone, but higher intensities are obtained for the positive polarity.

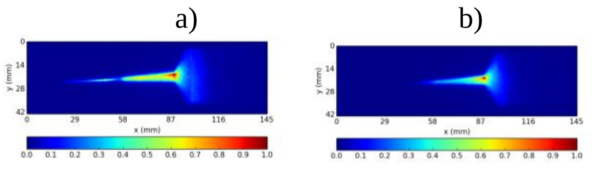

Figure 2: iCCD pictures, 24 µs exposure time pictures: a) positive polarity, b) negative polarity (2400 V and 2.3 L.min^{-1}).

We have investigated the spatiotemporal development of the plasma inside the dielectric cone. On figure 3 the discharge is recorded with 10 ns exposure time to observe the plasma inside and outside the device. For both polarities, the plasma is ignited between the electrodes inside the conical dielectric and moves along the tube. At the same time a front of excitation/ionization is expulsed in open air.

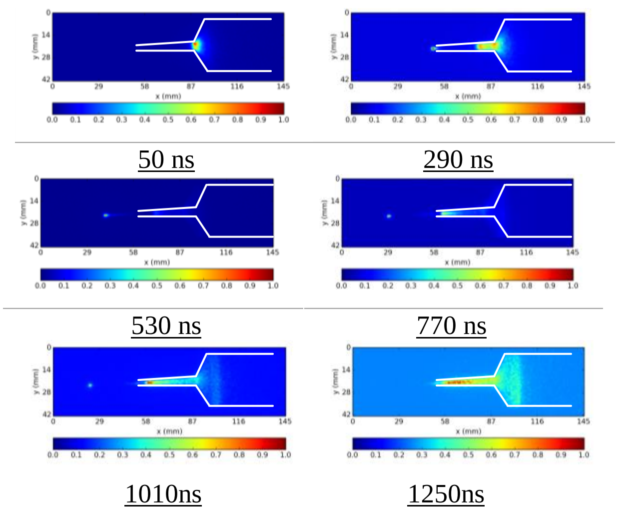

Figure 3: iCCD pictures taken at six different times for 10ns exposure time (2400 V and 2.3 L.min^{-1}).

On figure 4 the study is focused on the plasma jet development in open air for both polarities and 10 ns exposure time.

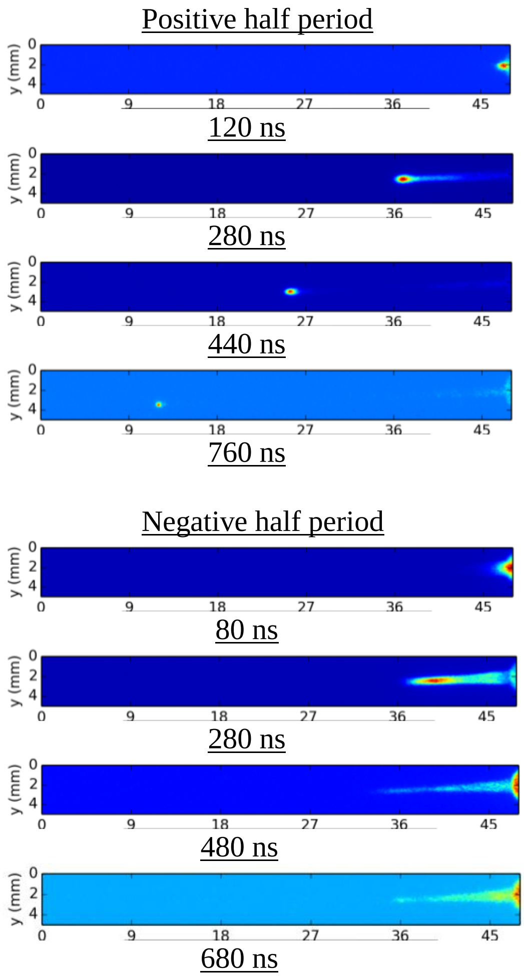

Figure 4: Spatiotemporal evolution of the discharge in positive and negative half period (2400 V and 2.3 L.min^{-1}).

In the positive half period the discharge appears as a “plasma bullet” [8] and in negative polarity the discharge is like a channel. These different propagation modes could be due to the different orientation of the electric field [9]. The “bullet” in the positive half period moves at an average velocity around 55 km.s^{-1} and the channel extends at an average velocity around 40 km.s^{-1}.

3.2 Excited species

On the figure 5, optical spectra lines intensities recorded in front of the jet are plotted.

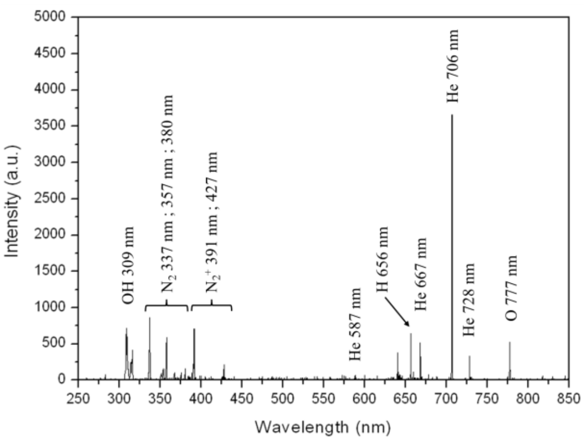

Figure 5: Helium plasma jet OES in open air (2300 V and 4.5 L.min^{-1}).

We can observe emission lines corresponding to the buffer gas He (587 nm, 667 nm, 706 nm and 728 nm) and others corresponding to ambient air species such as: O, H, OH, N_2 and N_2^+. The excited species H, OH and O correspond to the dissociation of H_2O, H_2 and O_2. The N_2 lines (337 nm, 357 nm and 380 nm) correspond to the second positive system and the N_2^+ lines (391 nm, 427 nm) correspond to the transitions of the first negative system.

Filters have been used with the iCCD camera in order to observe the spatial distribution of He, O, N_2 and N_2^+ within the jet in positive polarity. The results are shown on figure 6.

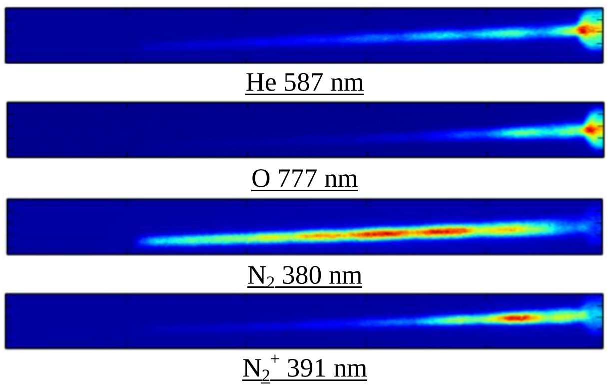

Figure 6: Spatial distribution of He, O, N_2 and N_2^+ in the plasma jet (2400 V and 2.3 L.min^{-1}).

He and O have their maximum intensities close to the end of the dielectric cone. Their intensities decrease rapidly with the distance. He metastable quenching is high in ambient air.

N_2 and N_2^+ have a different behaviour. Both lines reach their maximum some millimetres after the end of the dielectric cone and then decrease with the distance. N_2^+ reaches its maximum before N_2, but N_2 line stays longer along the jet.

N_2^+ is a result of the Penning ionization of N_2 by He metastable. The excitation and ionization of N_2 occur outside the device in open air.

4. Conclusion

OES and iCCD measurements results concerning our asymmetric DBD plasma source have been obtained. The plasma jet development in ambient air is polarity dependent. In the positive half period a plasma bullet is clearly observed moving fast at an average velocity around 55 km.s^{-1}. In the negative half period the plasma jet develops like a channel moving. Within the jet, excited and ionized species have been identified; they correspond to species of the carrier gas and species present in open air.

Further investigations are still being carried out to study the influence of the flow and the applied voltage on the evolution of plasma jet velocity.

5. Acknowledgment

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6. References

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