Characterization of helium plasma jet at atmospheric pressure touching water, metal and dielectric surface

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Abstract: Propagation of ionization waves generated in an atmospheric plasma jet, in interaction with different surfaces, is followed by an ICCD camera. The influence of different parameters such as helium flow rate, relative permittivity of the target and gap between plasma jet and surface is highlighted. The distribution of excited OH between the outlet of the plasma jet and the target is recorded with a photomultiplier associated with interferential filters and a photon counter. Time resolved cartography of excited species, treated with an Abel transform, are obtained with this method. In the case of low values of the relative permittivity of surface, a formation and propagation of surface ionization wave were observed. For high values of relative permittivity, a conduction channel was observed between the plasma jet and surface. Significant differences are also observed in the OH distribution when the permittivity was changed.

Keywords: plasma jet, imagery, ionization wave, excited species, reactive species.

1. Introduction

Atmospheric low temperature plasma jets are well known as effective sources of Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS). These species play an important role in many biological mechanisms when atmospheric plasma jets are used for biomedical applications [1]–[7] such as sterilization, chronic wound treatment, cancer treatment, etc. The electrical properties of the surface may significantly vary from case to case. For example, in the case of wound treatment the permittivity of the treated surface depends on healing process and humidity level of the wound [8]. In these cases, plasma jets are in contact with the treated surface that can modify the characteristics of the plasma jets and can significantly affect, in some cases, the plasma properties.

A better understanding of the mechanisms of propagation of the ionization waves and the reactive species production is required to optimize plasma sources for biomedical applications. In this paper, we investigate the propagation of helium plasma jet in the presence of three surfaces with different permittivity values. For this purpose, optical characterisations are achieved on the plasma jet in presence of three different targets: pure water (Milli-Q), metal linked to the ground and dielectric. The distribution of helium flow propagating from the exit of the plasma device is studied by schlieren imaging and the impact of the gap between plasma jet and surfaces is analysed. OH production throughout the plasma jet is also flowed.

2. Experimental setup

The plasma jet device is based on dielectric barrier discharge configuration as previously described [9]. Two aluminium electrodes are wrapped around a quartz tube. A generator delivered high voltage mono-polar square pulses between them. Characteristics of the power supply are as follow: 10 kV voltage, 10 kHz frequency and 1µs pulse duration. Helium is delivered through the quartz tube with a flowmeter and the flow rate can be varied from 0 to 15 L/min. The surfaces upon which the jet is incident are: Milli-Q water 42 ml in a petri dish with a relative permittivity of 80, metal plate of steel linked to the ground with an infinite relative permittivity and dielectric surface (glass slide) of 1 mm thickness with a relative permittivity of 5.

For optical analyses, ICCD pictures are acquired with and ICCD camera equipped with a photographic lens (fixed focal length of 60 mm). The picture acquisition is synchronised with the discharge ignition with a delay generator DG645. For this acquisition, transparent electrodes are used to observe the generation and the propagation of the ionization wave inside the quartz tube which compose the plasma jet. The fluid-dynamic behaviour of the plasma jet was investigated through a schlieren imaging setup in a Z configuration composed of a LED array (Bidgelux BXRA 3500) LED, a pinhole, two parabolic mirrors with a focal length of 1 m, a razor edge positioned vertically and an ICCD camera equipped with a photographic lens of 200 mm focal. The plasma jet has been positioned vertically in the middle of the optical path between the two parabolic mirrors. For time resolved mapping of OH emission, photons are collected by a photomultiplier associated with interferential filter centered at 313 nm with 10 nm bandwidth. The number of photons collected from different spatial positions of the plasma jet is an image of the relative density of excited species. The time resolved emission is recorded by a photon counter (5 ns resolution) at different position spaced in a grid between the jet outlet and the target. The time resolved mapping of excited species are treated with an Abel transform in order to obtain the radial distribution of the relative density of excited species in the plasma.

3.Results

The Fig. 1.a shows the propagation of the ionization wave in the case of pure water surface at 20 mm from the tube outlet and for a helium flow rate of 3 L.min^{-1}. The ionization wave propagates along the inner dielectric surface of the tube and reaches the ambient air. The impact of the ionization wave on the water surface leads to the formation of a conductive channel between the surface and the jet, and the formation of a surface ionization wave on the water surface. The propagation mechanisms of the ionization wave after impact on the surface is impacted by the characteristics of the treated material, especially its relative permittivity and its electrical conductivity (figure 1.b). A low relative permittivity allows the spreading of the ionization wave along the surface. A high relative permittivity leads to the formation of a conductive channel between the surface and the plasma jet.

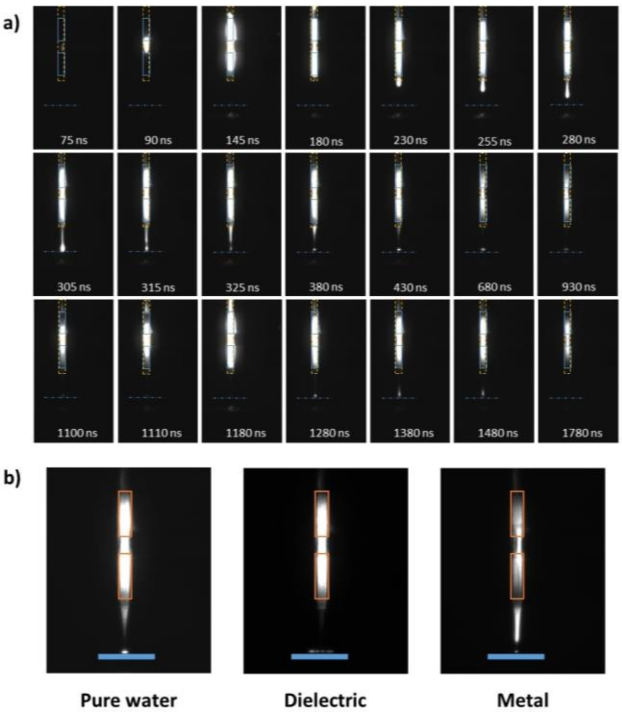


Fig. 1. ICCD pictures of the plasma jet during the evolution of the voltage pulse with a pure water surface at 20 mm of the jet outlet.

The Fig.2 presents the modification of the helium flow interacting with a surface as function of the surface permittivity and the gap between plasma jet and surface. The helium flow rate is fixed at 2 L.min^{-1}.

When discharge is off, no significant differences are observed for the different surfaces Fig 2.a. When the discharge is switched on Fig 2.b, first we can observe that the discharge ignition allows a better spreading of the helium flow on the surface.

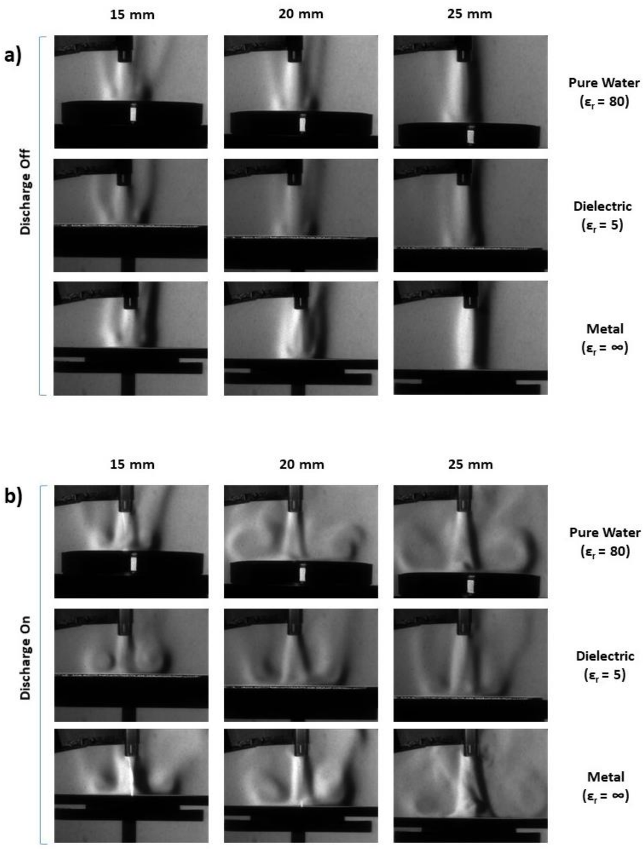
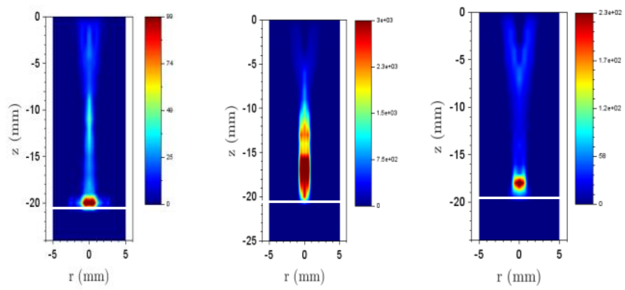


Fig. 2. Schlieren images of the plasma jet for different value of gap width and for different surfaces with and without discharge. Helium flow rate 2 L.min^{-1}.

Furthermore, the discharge ignition leads to the formation of vortex structures. As can be seen in Fig.2.b, these two effects increase as the relative permittivity of the surface treated increases. These effects can be related to the formation of a conductive channel for high relative permittivity surfaces and a more important energy deposition that can lead to gas heating and an increase of gas velocity.

Time integrated mappings of excited OH for the three surfaces with different relative permittivity can be seen in Fig.3. We can notice that a low quantity of OH is formed when the plasma jet interacting with a low relative permittivity surface like glass, despite a spreading of the excited OH on the surface along some millimetres. On the contrary, the intense conductive channel formed when the plasma jet interacting with a high relative permittivity surface like metal leads to the formation of a high density of excited OH inside the conductive channel. But in this case, the conductive channel is highly located on the surface and there is no spreading of the excited OH. Finally, with a pure water surface interacting with the plasma jet, we can observe a hybrid behaviour of the plasma as the impact of the ionization wave on the surface leads to the formation of a conductive channel and the formation of a surface ionization wave. In any case, we can notice that the excited OH is mainly formed near the surface. The impact of the helium flow rate applied to the plasma jet and the gap between the surface and the jet was also studied (data not shown). These parameters have an impact on the formation of the conductive channel, and the density of excited OH.



(a) **(b)** **(c)**

Fig. 3. Time integrated mappings with Abel transform of the excited OH molecule for 3 surfaces at 20 mm of the jet outlet: (a) a glass surface (ε_r =5), (b) a grounded metallic surface ($\varepsilon_r = \infty$) and (c) a pure water surface (εr = 80). Helium flow rate 3 L.min-1

4.Conclusion

The plasma jet generates ionization waves that interact in different way with surfaces depending of the relative permittivity and the electrical conductivity of the treated surfaces. The ionization wave spreads over a low relative permittivity surface and forms a conductive channel between a high relative permittivity surface and the jet. The generation of ionisation waves has important effects on the helium flow distribution, such as the better spreading of the helium flow on a surface and the formation of vortex structures. The excited OH is formed on the propagation way of the ionization wave and the formation of a conductive channel for high relative permittivity surfaces increases the excited OH density generated by the discharge.

5.References

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