Characterization of a kHz atmospheric pressure plasma jet: measurements of the electric field, electron properties and other plasma parameters

Marlous Hofmans[1,2], O. Guaitella[1] and A. Sobota[2]

[1]LPP, CNRS, École Polytechnique, Sorbonne Université, Université Paris-Saclay, Observatoire de Paris, 91128 Palaiseau, France
[2]EPG, Eindhoven University of Technology, Postbus 513, 5600 MB, The Netherlands

Abstract: Multiple diagnostics are applied to determine different plasma parameters in an atmospheric pressure helium plasma jet, that is powered by ambipolar µs long voltage pulses at kHz frequency with an amplitude of several kV. Stark polarization spectroscopy, Thomson and Raman scattering, optical emission spectroscopy, ICCD imaging and the Schlieren diagnostic are used to characterize the plasma jet.

Keywords: plasma jet, atmospheric pressure, diagnostics, electric field, plasma parameters

1. Introduction

Cold atmospheric plasma jets are widely studied for their (biomedical) applications to modify or treat materials, for example to treat wounds or tumours, or to modify surfaces. For all these applications, as well as for optimization and modelling of the plasma, it is important to know the parameters of the plasma, such as the gas temperature, electron temperature and density, and electric field. All these parameters have been measured in this work, using multiple diagnostics.

2. Experimental setup

A cold atmospheric pressure plasma jet, in the same configuration as [1] and [2], is used with helium (1.5 slm) as feeding gas. The jet is powered by unipolar (positive) pulses with varying duration, frequency and amplitude, but the general settings are a duration of 1 µs, a repetition frequency of 5 kHz and an amplitude of 6 kV. In Fig. 1a, a schematic overview of the jet is shown. The jet is operated vertically, downwards.

Multiple diagnostics are used to characterize the plasma jet. Except for Stark polarization spectroscopy, they are all incorporated in the same setup, which can be seen in Fig. 1b. The main diagnostic is Thomson and Raman scattering and for this the same setup is used as in [3]. The jet is placed such that the capillary exit is just above the focal point of a 532 nm Nd:YAG laser, which operates at 100 Hz with 140 mJ per pulse. The laser scattered signal is focussed into a glass fiber, after which the Rayleigh scattered light is filtered out with a volume Bragg grating as Notch filter. The remaining Thomson and Raman scattering signal is focussed into the spectrometer, where the signal is captured by an ICCD camera. Thomson scattering originates from the scattering on free electrons,

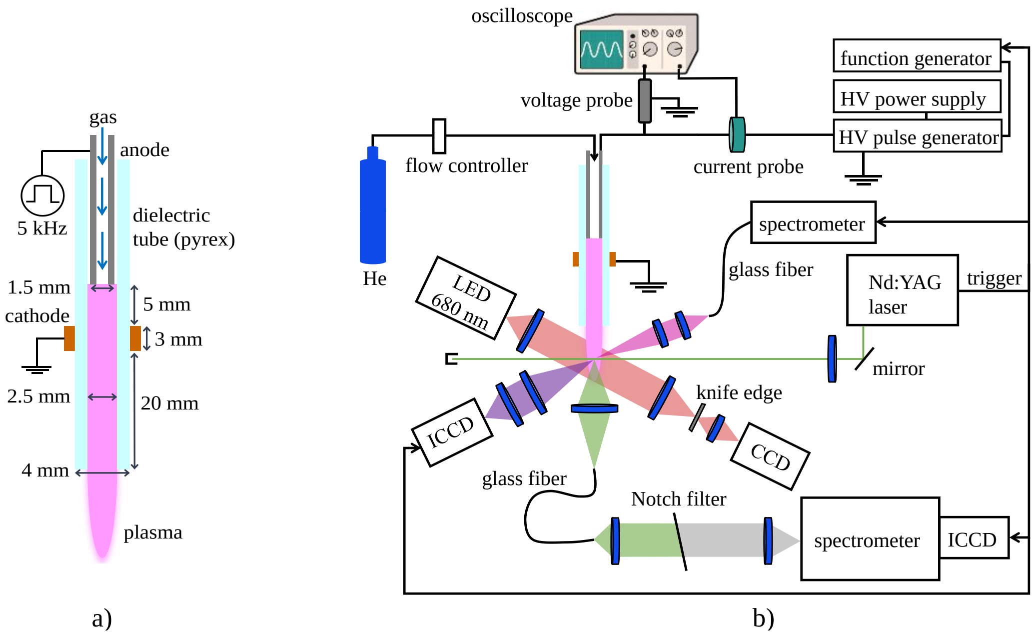

Fig. 1. Schematic overview of (a) the plasma jet [2] and (b) the experimental setup.

therefore, the electron density and temperature can be determined from this. Raman scattering originates from scattering on molecules and therefore from this the gas temperature and the density of nitrogen and oxygen molecules can be determined in this plasma. The clock of the laser is used to synchronize the plasma with the laser, and it is also used to trigger other diagnostics present in the setup, as can be seen in Fig. 1b.

ICCD imaging is used to align the plasma jet well in the focal point of the laser for Thomson and Raman scattering, but is also used to observe the plasma jet at the different settings (e.g. different duration, frequency and amplitude of the applied voltage pulses).

Optical emission spectroscopy is performed to observe the evolution of the different species in the plasma jet. The light emission of the jet is focussed into a glass fiber that leads to a spectrometer that is sensitive in the range 350 – 900 nm.

The Schlieren diagnostic is used to image the flow in the plasma jet. Two large lenses are placed around the jet, through which the light of a broadband LED with a center wavelength of 680 nm is focused on a vertically placed knife edge. The resulting light is focused on a CCD camera.

The electric field is measured using the Stark polarization spectroscopy setup, described in detail in [2]. A spectral line of helium is studied, from which the peak-to-peak wavelength difference between the allowed and the forbidden band determines the electric field following the derivation, also given in [2]. The electric field that is measured here is the macroscopic electric field at the head of the plasma bullet (also called ionization wave or ionization front).

3. Results

The profile of the electric field in the plasma jet as a function of the distance from the anode is shown in Fig. 2. It can be seen that the field decreases inside the capillary as the bullet moves away from where the plasma is created, and then increases when the bullet enters the ambient air. This increase can be explained by the fact that bullet contracts as oxygen and nitrogen from the ambient air admix with the helium of the plasma.

From the Thomson and Raman scattering results it is found that the electron density and the gas temperature follow the same behaviour as the electric field, *i.e.* an increase outside the capillary with a maximum around the same position as the electric field. The density of N_2 and O_2 also increases with an increasing position down the jet, but it keeps increasing and does not show a maximum around the same position.

A radial profile is taken at two different axial positions in the jet, namely at 3 mm and 8.7 mm away from the end of the capillary. Measurements are taken with the plasma on and with the plasma off, leaving the gas flow on. The profiles resulting from Raman scattering and from Schlieren imaging show similar behaviour.

Measurements are also performed to study the influence of the varying frequency, length and amplitude of the voltage pulses applied to the plasma jet, by keeping all parameters constant except for the one that is studied. Influences are observed in all studied parameters as well as in the intensity of the spectral lines, although the influence is not always significant.

When a floating metal target is placed under the plasma jet, at 1 cm from the end of the capillary, it is found to have a profound influence on all measured parameters. From ICCD imaging it is also seen that the behaviour of the plasma above the metal target is significantly different than in the freely expanding plasma jet.

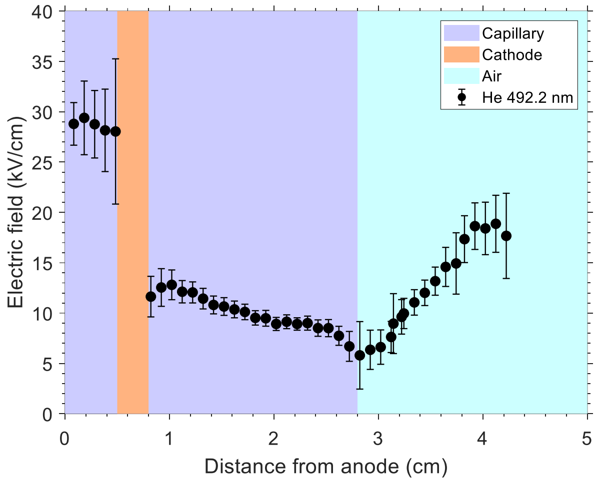

Fig. 2. The electric field in a freely expanding jet as a function of distance from the anode. [2]

4. Conclusions

Multiple diagnostics have been applied to an atmospheric pressure helium plasma jet, yielding valuable information on multiple plasma parameters, such as the electric field, the electron temperature and density, the gas temperature, and the density of N_2 and O_2. It is the first time that all these parameters have been measured in the same plasma source. From the results of the different diagnostics, a strong coupling is found between the gas mixing and the electron properties in the plasma jet. The influence of different settings in the applied voltage of the plasma jet is also studied. In general, the different diagnostics give consistent results.

5. Acknowledgements

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6. References

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