Time and space evolution of plasma bullets in APPJ applied for human tissue treatment

A.V. Nastuta, I. Topala, V. Pohoata, G. Popa
Plasma Physics Laboratory, Faculty of Physics, Alexandru Ioan Cuza University of Iasi
Bd. Carol I, No. 11, 700506 Iasi, Romania
e-mail: andrei.nastuta@uaic.ro

Résumé

Plasma Medicine is a new interdisciplinary field developed in the last years that brings into biology and medicine new techniques from the plasma community. Many directions that involve plasma physics and biotechnology are in study nowadays in numerous laboratories. In this paper we present results related to the optical and spectroscopic diagnosis of a helium atmospheric pressure plasma jet, designed for medical applications, especially human tissue treatment.

Introduction

The increasing amount of reports and scientific publications related to the Plasma Medicine and its benefice / risks reflect the importance of plasma technologies use in fields like biology and medicine [1]. Atmospheric pressure jet discharges are known in literature under many names, such as: plasma pencil, plasma needle and atmospheric pressure plasma jet (APPJ). The variety of the atmospheric pressure plasma jet can be classified using different parameters such as: working gas, repetition frequency of the applied voltage pulse and the electrodes configuration. These parameters can be used in order to start a standardisation of the APPJ for bio-medical day-to-day use. In this study, an APPJ in helium with impurities was generated in a cylindrical dielectric barrier discharge (DBD) configuration and was characterized using spatio – temporal resolved optical emission spectroscopy and ultrafast photography.

APPJ set-up

The experimental arrangement of the plasma jet designed in our laboratory is shown in fig. 1. We used a quartz tube (inner diameter 4 mm, outer diameter 6 mm) with one copper slit electrode. High voltage pulses, 2 kHz frequency, 260 µs width and 4 kV amplitude, are applied from an amplification chain: a high voltage amplifier (Trek Inc.), driven by a square pulse waveform generator (Tabor Electronics Ltd.). Helium (spectral purity) was used as working gas for the APPJ, at a flow rate of 3 slm (2.5 m/s, calculated speed) [2].

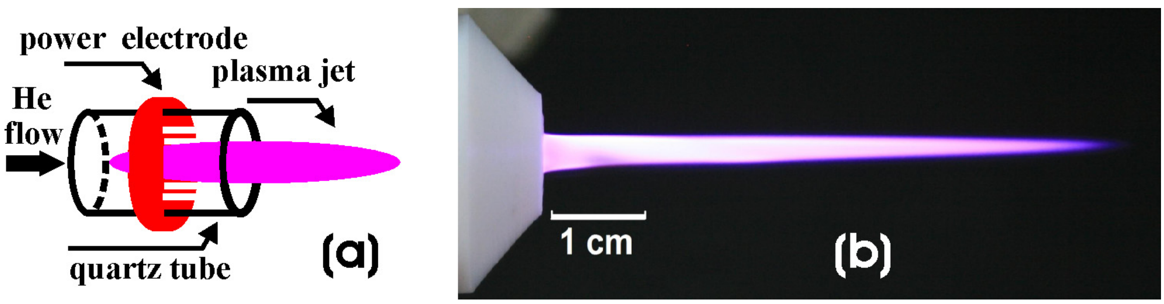

Fig. 1: (a) Scheme and (b) photo of our APPJ.

The discharge properties were analyzed by optical emission spectroscopy and ultra fast imaging. The light emission from the DBD plasma jet was collected through a slit with an optical fibre placed at 5 mm from the plasma jet, and then analyzed with a high resolution Triax 550 (Horiba Jobin Yvon) spectrometer equipped with a Symphony CCD (Horiba Jobin Yvon) and a Hamamatsu photomultiplier as detectors. The optical emission spectra were collected in different positions of the jet's principal axis in order to identify and to monitor the plasma active species. The rotational and the vibrational temperature of excited molecules in the plasma volume were calculated from the high resolution spectra of nitrogen molecular ion (N_2^+) at 391 nm and the second positive system of molecular nitrogen (N_2). An ICCD camera (Hamamatsu C8484-05G) was used to capture 50 ns exposure time photos of the plasma jet, for a better understanding of its dynamics.

Spatial resolved optical emission spectroscopy and ultra fast imaging

The APPJ spectrum contains lines from helium transitions, the plasma working gas, and signatures of impurities, such as reactive oxygen species (ROS) and reactive nitrogen species (RNS), as shown in fig 2(a). More precisely the optical emission spectrum of the APPJ consist of the following atomic lines / molecular bands: OH radical – at 308.9 nm as a result of H_2O dissociation, N_2 – at 337 nm as dominant component of the ambient air, N_2^+ - at 391 nm, an helium metastable presence indicator, He – at 706 nm as plasma working gas, O – at 777 nm and 845 nm as a result of H_2O dissociation as well. The axial dependence of these lines or bands is analysed and discussed. From the rotational and vibrational spectra of N_2^+ and N_2 we determined the rotational temperature, $T_{rot} \approx 470$ K, and vibrational temperature, T_{vib} from 3500 to 2500 K.

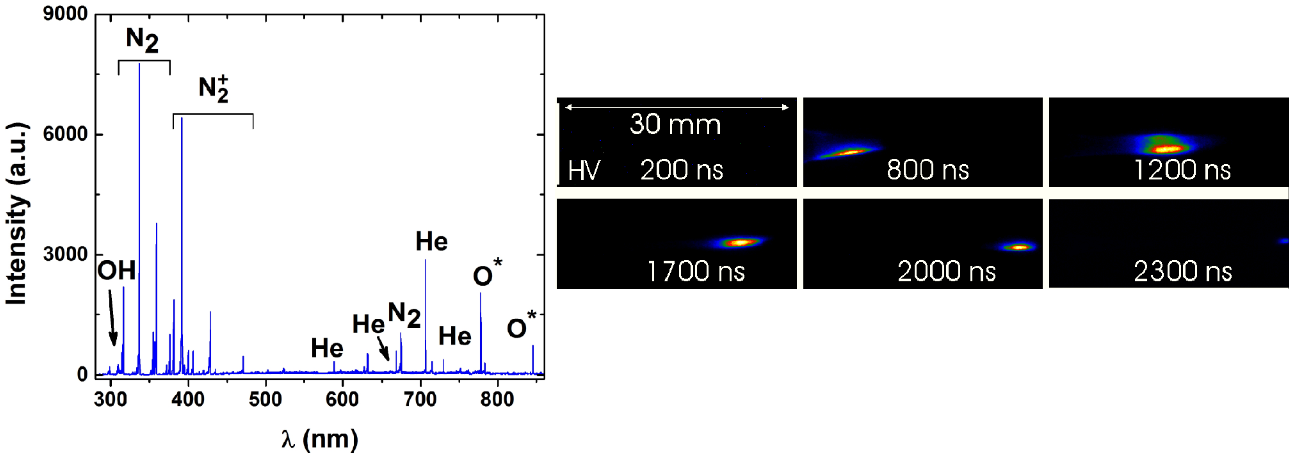

Fig. 2: The APPJ (a) emission spectrum and (b) 50 ns exposure ICCD images

The ultra fast imaging investigations (Fig. 2(b)) show that our APPJ has a bullet-like behaviour. The propagation mechanism of this type of discharge can be describe either by an ionization model [3-4] or a streamer model [5]. The high speed plasma structures reach velocities, calculated from ICCD images, ranging between 0.1 to 14 × 10^4 m/s outside the discharge tube. The plasma bullets velocities can be determined also using a photomultipliers (fast response time).

Conclusion and perspectives

The APPJ in helium, in our experiments, have many reactive species (N_2, N_2^+, OH, O^*), their evolution, in time and space being important for medical application. The rotational, as well as the vibrational, temperature was determined to be around 470 K, respectively between 3500 – 2600 K.

Using an ultra fast camera (ICCD) plasma bullets velocities were determined to range between 0.1 to 14 × 10^4 m/s. This peculiar spatio – temporal behaviour of the APPJ must be correlated with its biological effects (e.g. healing), since tissues or biomolecules exposed to this kind of plasma jet are irradiated with temporal and spatial noncontinuous plasma structures.

References

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