Generation of reactive oxygen species in kHz-driven atmospheric pressure plasma jets for biomedical applications

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Résumé

We have developed a kHz-driven plasma jet for the generation of reactive oxygen species for biomedical applications. When operated in helium with small oxygen admixtures, our jet device produces stable non-equilibrium "plasma bullets" at atmospheric pressure. These small and fast plasma packets are emitted into ambient air, and, thus, able to carry several species into biological targets positioned some centimeters away. Optical diagnostics of the effluent region have been performed, allowing the measurement of singlet delta oxygen and ozone absolute densities. High concentrations of these reactive oxygen species (10^{14}–10^{16} cm^{-3}) have been obtained at 5–15 cm downstream. Moreover, it has been observed that the control of the jet operating conditions enables to tailor the reactive oxygen species composition of the effluent towards different biomedical applications, from fundamental biochemical studies to therapeutic treatments, through sterilization and bio-decontamination.

Introduction

Cold plasma jets produced by pulsed discharges have recently attracted a lot of attention because of their unusual physical properties that enable the development of new applications, particularly for biomedical applications. The current interest in this type of atmospheric pressure discharge stems from the fact that they provide a means of delivering, at ambient pressure and temperature, reactive plasma species/elements (radicals, positive or negative ions, electrons, UV radiation), and not only long-lived afterglow species, to a target located some centimeters away from the main discharge zone. In fact, the plasma is not spatially confined by the electrodes, and intensified charge coupled detector (ICCD) pictures of these jets revealed that they were not continuous plasmas but were composed of "comet like" discrete plasma pulses (commonly known as "plasma bullets") propagating at very high velocity, much greater than the discharge gas velocity [1]. These stable non-thermal plasmas can travel several centimeters in the ambient air to deliver reactive species to the surface of a biological sample.

Many different kinds of cold plasma jets have been developed [2–5]. The simplest type of these sources consists of a dielectric tube with two tubular metal electrodes and a noble gas flowing through (linear tube jet) [6]. As shown in Figure 1, the plasma jet design investigated in this work is composed of a capillary dielectric tube (quartz) with inner diameter of 4 mm and outer diameter of 6 mm. Tubular copper electrodes (2 mm wide) are assembled around the tube separated by a few centimeters from each other. The powered electrode is driven with a 20 kHz pulse repetition and high voltage (4–10 kV) supply. The electric field is directed parallel to the gas flow. Helium is used as the main discharge gas carrier with 1–6 slm flow rate. The plasma jet is operated in He/O_2 mixtures (O_2 <2%), and the effluent is emitted into ambient air. An intense plasma forms inside the glass tube between the two electrodes, and a relatively long pulsed plasma plume (few cms) emerges at the end of the capillary tube. The length of the plume has been found to depend on the operation parameters (e.g. applied voltage, gas flow rate).

With the increasing development and usage of plasma devices in the treatment of living tissue and the full effects of its application on DNA still unknown, much research still needs to be carried out in this area. This work intends to improve the understanding of how plasma treatment can affect DNA by correlating measured reactive oxygen densities in the effluent of a plasma jet to its influences on DNA. In our experimental setup, DNA solutions can be placed in wells and placed in front of the plasma effluent (cf. Figure 1). As it has been recently demonstrated [7,8], exposure to oxygen-containing atmospheric plasmas can result in DNA damage. In the present work, absolute densities of reactive oxygen species are measured by different optical methods: singlet delta oxygen (SDO) by infrared emission spectroscopy [9], and ozone (O_3) by ultraviolet absorption spectroscopy. These densities can be directly correlated with

DNA damage, which allows attribution of species to certain types of damage, and gives scope to tune the plasma for desired effects.

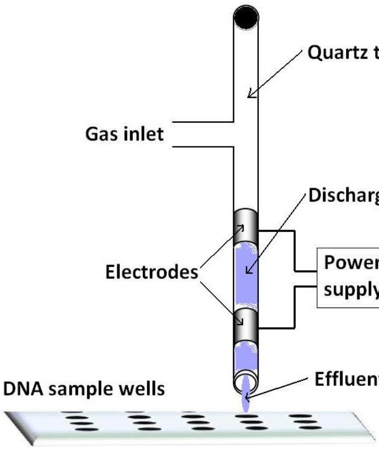

Fig. 1: Schematic of the kHz-driven atmospheric pressure plasma jet.

Results and discussion

The effect of different parameters, such as gas flows and mixtures, and power coupled to the plasmas, on the production of O_3 and SDO by the plasma jet has been studied. High concentrations of these reactive oxygen species (10^{14}–10^{16} cm^{-3}) have been obtained at 5–15 cm downstream. As exemplified in Figure 2, by controlling the discharge operating conditions, we are able to tailor the reactive oxygen species composition of the jet effluent. While at very low oxygen concentration in the gas mixture (~0.3%) similar densities are measured for O_3 and SDO, the density ratio of O_3 to SDO increases considerably with increasing oxygen admixture, up to 30 at about 1.5% of oxygen. In order to determine the relevance of these reactive oxygen species in DNA oxidation, studies of the interaction of DNA solutions with the jet effluent are currently in progress.

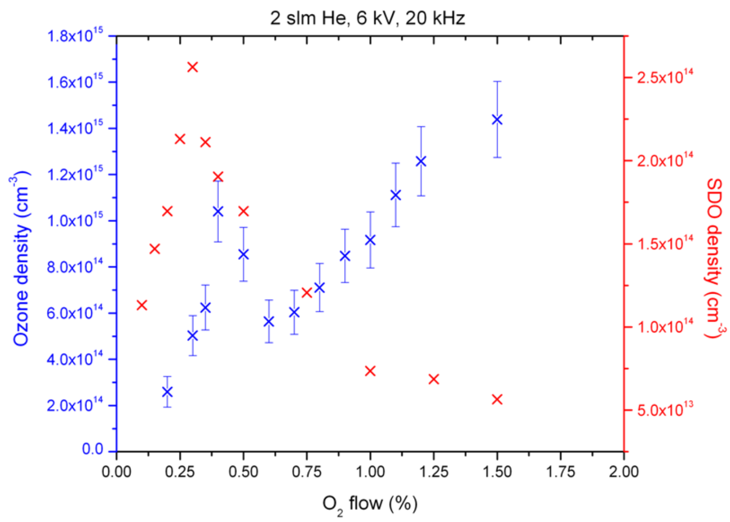

Fig. 2: Evolution of the SDO and the O_3 densities as a function of the oxygen fraction while operating the plasma jet at 6 kV and at 20 kHz, in a He/O_2 mixture, with a He flow of 2 slm.

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