Transfer of Pulsed Atmospheric-pressure Plasma Stream generated by a plasma gun

V. Sarron, E. Robert [(*)], D. Riès, S. Dozias , J.M. Pouvesle

Groupe de Recherche sur l'Energétique des Milieux Ionisés, GREMI
UMR 7344, Université d'Orléans/CNRS, BP 6744, 45067 Orléans cedex
[(*)] eric.robert@univ-orleans.fr

The plasma gun, developed in GREMI, generates Pulsed Atmospheric-pressure Plasma Streams (PAPS) which propagate in dielectric capillaries or tubes. PAPS transfer can be induced by inserting metallic section along the plasma propagation path or via the plasma plume, generated at the capillary outlet, across the wall of rare gas flushed dielectric tube. Both electric field generated in the PAPS ionization front edge and charge transfer process are shown to be involved for PAPS transfer. Besides offering new insight in the PAPS propagation studies, these results open up new possibilities for non-thermal plasma delivery through dielectric or metallic or electrode-less capillaries.

The plasma gun, developed in GREMI, is based on a dielectric barrier discharge (DBD) flushed with rare gases, at low flow rate (from few tens $cm^3.min^{-1}$). Pulsed Atmospheric pressure Plasma Streams (PAPS) generated by the plasma gun, at high velocities (10^8 $cm.s^{-1}$), can propagate over tens of centimeters to reach the capillary outlet and generate a plasma plume in air. Generation and propagation mechanisms are investigated by means of ICCD imaging and ionization front velocity measurements obtained with a set of optical fibers connected to a PMT. Behind a better understanding of PAPS properties, PAPS transfer studies should open up new possibilities for atmospheric pressure plasma delivery.

Once voltage is applied to the DBD of the plasma gun, a plasma is generated and propagates in a wall hugging mode (Wh-PAPS) over the first centimeters [1]. Along PAPS propagation, plasma front switches to a more homogeneous mode (H-PAPS). PAPS velocity decreases exponentially from the source to an extreme position, where PAPS vanishes. The longest PAPS length propagation is voltage pulse shape dependent and relies on the connection of the ionization front with the DBD reactor through a plasma "tail" behind the PAPS front edge [2]. The PAPS propagation is clearly related to plasma tail impedance which directly affects the voltage drop between DBD reactor and PAPS front.

PAPS transfer can be induced by inserting a metallic section along PAPS propagation (fig. 1a)), or impinging a gas flushed tube by the plasma plume (fig. 2a)) [3,4] created at the outlet of the plasma gun capillary. PAPS transfer occurring with metallic section, such as inox tube, preserves the PAPS propagation characteristics. The overall PAPS propagation length in borosilicate is preserved in addition of the metallic tube length, and the PAPS velocities measured at both extremities of the metallic tube are almost similar, whatever its length. From electrical point of view, metallic tube simply acts as a conductive element in serie with the plasma impedance.

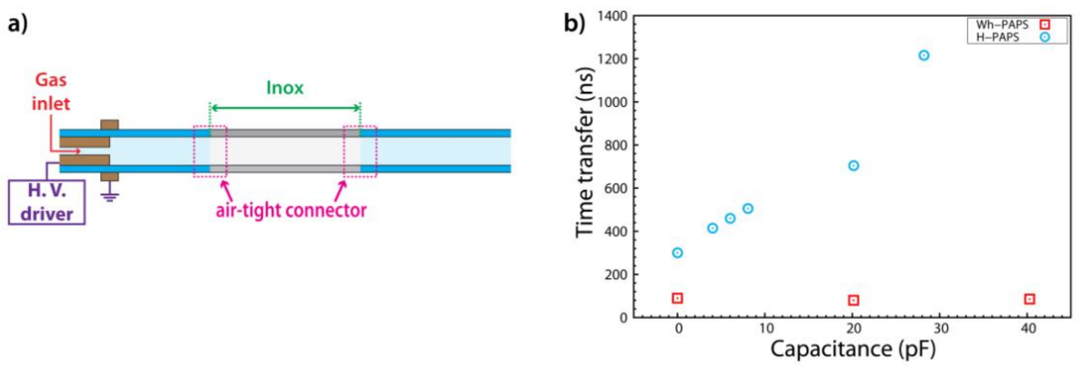

Fig. 1: a) Experimental set-up. b) Measurement of the time transfer, as a function of capacitance induced by inox capillaries.

The high electric field induced by the ionization front polarizes the metallic section, and allows the generation of a new PAPS at the metallic tube outlet. This new PAPS has the same characteristics as the incident PAPS regarding the propagation length and velocity. Nevertheless, this transfer is not immediate and time transfer, *i.e.* time between inlet and outlet, depends on PAPS mode and on the capacitance induced by the metallic section. The capacitance influence on the time transfer, as a function of PAPS mode, is illustrated in figure 1b). Wh-PAPS present a much smaller electrical resistance than H-PAPS and act almost as an electrical wire. Conversely, H-PAPS time transfer increases with length, indeed with value of the induced capacitance. A time integrated plasma impedance, during voltage pulse application, of few tens of kilo Ohms has been estimated for H-PAPS. This suggests that, for H-PAPS, the transfer is governed both by polarization and capacitor charging and discharging.

When the plasma plume from a primary plasma gun impinges a gas flushed dielectric tube, it is possible to generate two PAPS in the latter. This transfer is not always instantaneous and depends on the dielectric wall. Secondary PAPS appear immediately in case of Rilsan® while for borosilicate glass, it needs few shots before ignition. PAPS velocity measured before and after transfer shows the same behaviour as the PAPS velocity for the same length in a 25 cm long straight borosilicate capillary (fig. 2b)). In the case of transfer, the PAPS propagate first in a 15 cm long borosilicate capillary, then through 4 mm ambient before transferring through the dielectric wall. Transferred PAPS velocity, in the second borosilicate capillary, is in continuation with the incident PAPS velocity. PAPS generation, induced in the second dielectric guide, is of the same nature than in the initial capillary, i.e. the two propagation modes are observed, see fig. 2c). Once transfer is ignited, a plasma is generated from the impinged side and propagates radially to the other side of dielectric guide. Then the PAPS hug the wall to switch to a more homogeneous plasma. As mentioned earlier, the transfer through the dielectric wall, preserves PAPS propagation characteristics. The high electric field generated at the tip of the plasma plume, and the accumulation of charges on the dielectric outer surface are supposed to be the major mechanisms leading to observed phenomena.

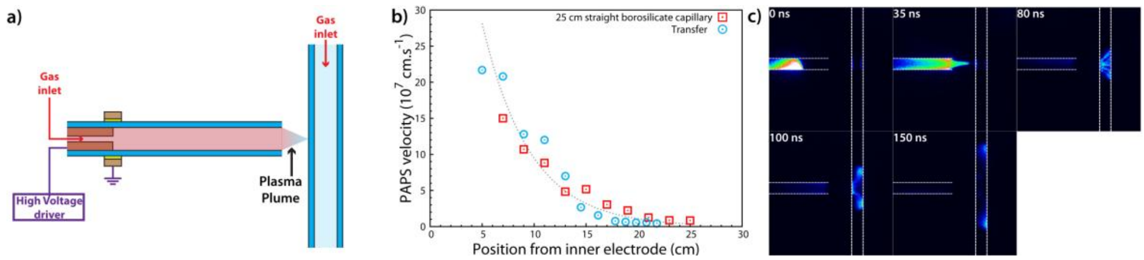

Fig. 2: a) Experimental set-up. b) PAPS velocities for a 25 cm straight capillary, and in the case of the set-up described in figure 2a). The gap between the two capillaries is 4 mm. c) One nanosecond snapshots of PAPS transfer through a borosilicate capillary flushed with Neon. The time in each picture indicates the delay from an origin instant given in the “0ns” picture.

PAPS transfer potentialities could be very helpful for biomedical applications, notably for endoscopic plasma delivery including metallic parts (e.g. catheter, needles) or plasma delivery through electrode-less capillary.

This work was supported by ANR ”PAMPA” and by Région Centre through the APR program ”Plasmed”. V.S. was financially supported by Conseil Général du Loiret. DR was financially supported by Région Centre and CNRS. Authors are grateful to Drs. Z. Xiong and M.J. Kushner for preference share about their in press publication [1].

References

[1] Z. Xiong and M.J. Kushner Plasma Sources Sci. Technol. (in press 2012)

[2] E. Robert, V. Sarron, D. Riès, S. Dozias, M. Vandamme, J.M. Pouvesle Plasma Sources Sci Technol submitted.

[3] S. Wu, Z. Wang, Q. Huang, Q. Xiong, X. Lu IEEE Trans. Plasma. Sci **39** (2011) 2292-2293.

[4] Q.T. Algwari, D. O’Connell IEEE Trans. Plasma. Sci **39** (2011) 2368-2369.