Effects of argon pulsed injection on a surface-wave plasma column at low pressures

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A widely-spread method for the deposition of functional coating deals with aerosol assisted processes [1], [2], [3]. The procedure includes introducing micrometre-sized droplets into the gas phase directly within the downstream plasma process. In this type of injection, employing pulsed aerosol spraying into the plasma is preferred over continuous injection [4]. This arises from the fact that an equilibrium state is re-established between each pulse, facilitating a better control over the deposition process [5]. However, the effects of pulsed injection on the plasma behaviour are not further documented in the literature.

This work focuses on the study of the behaviour of a plasma under the pulsed injection of gas. For their versatility and stability, a surface-wave plasma is used [6],[7]. It consists in a high-frequency, self-sustained discharge, that allow the creation of stable plasma columns over a wide range of operating conditions. For example, it works in a stationary state on a wide range of pressure from a few mTorr to atmospheric pressure [8]. The aim of this work is to characterize the surface-wave plasma characteristics with a pulsed gas injection and lay the groundwork for studying pulsed-aerosol injection.

This study focuses on the results obtained from investigating an argon (Ar) plasma sustained by a 915 MHz electromagnetic wave launched by a Surfatron and propagating along a dielectric tube with a 30 mm diameter. An injection system operating in a pulsed mode from Kemstream (Montpellier, France) was connected to the upper limit of the dielectric tube, so that the gas was sprayed downstream directly into the plasma. The pulsed injection introduced a temporal evolution of pressure determined by the injection time and frequency. Here, we set these parameters to 4 ms Ar pulse at 0.1 Hz. The latter induced a relatively weak pressure increase of approximately 50 mTorr from the base pressure at 1 mTorr. To characterize the dynamic behaviour of the plasma column, rapid imaging (12000 fps) was performed using a FASTCAM APX RS Photron.

Fig. 1-left reports snapshots of the plasma along a pulsed injection: it can be seen that the plasma column varies along the pulsed gas injection period. In stationary state, the latter is directly controlled by the balance between the power injected and the collisions. For example, from 10^{-5} to 10^{-1} Torr, the electron density and, consequently, the plasma length increases as described in the literature [9].

However, in the pulsed mode, the response is more complex (Fig. 1-right): the length sharply decreases with the pulsed injection, just before increasing and finally going back to equilibrium. Considering the balance between power deposition and collisions, one would expect that this behaviour varies with the injection conditions. However, independently of the injection parameters, and consequently, the pressure drop, the plasma column follows the same behaviour.

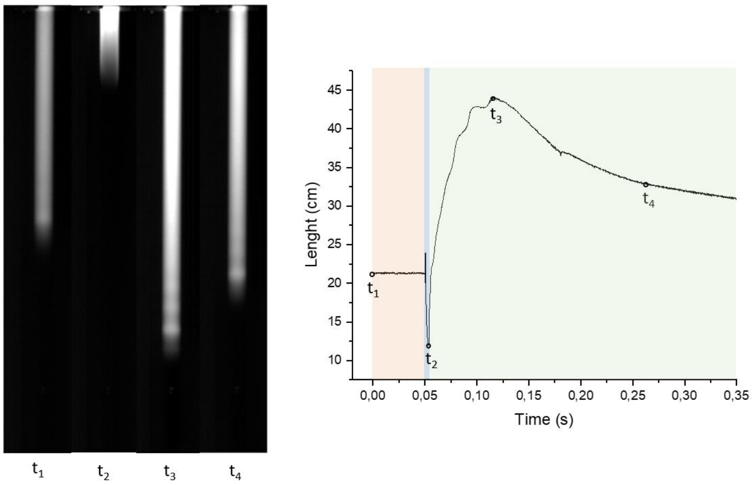

Fig. 1: Effects of argon pulsed injection along the pulse period with an injection time of 4 ms and frequency of 1 Hz – the discharge was obtained with 60 W. Rapid imaging enable to a) image the plasma column at different times along the pulse and b) plot its time evolution. The pulses are reported at different times t, in the the moments before (red), during (blue) and after the pulse (green).

As the pressure increase is relatively small, the behaviour of the plasma was hypothesized to be related to the pressure gradient or the gas flow rate rather than to the pressure difference. This hypothesis is confirmed by further experiments performed by introducing a diaphragm (2 mm in diameter) between the injection head and the plasma column to reduce the flow rate. With a head loss of 99.6%, the plasma column now varies directly with the gas pressure.

Hence, surface-wave plasmas sustained in the presence of pulsed gas injection are highly controlled by the gas flow rate. This can be attributed to the flow dynamics of the gas entering the tube and causing instabilities to the equilibrium of the self-sustained plasma.

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