Consequences of slightly different ground configurations on the propagation of ionisation waves inside capillary tubes

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Plasma jets which are intensively studied for biomedical applications are essentially ionisation waves, also named "guided streamers" propagating being confined into a small diameter tube. The properties of the jet at the output of the capillary tube depends strongly on how the discharge sustain itself all along the propagation. A capillary discharge in He is studied with fast imaging and electrical measurement with different grounded cylinder surrounding the capillary tube. The light intensity as well as the velocities measured exhibit a strong modification of the discharge behaviour even for small modification of the surrounding groud.

Plasma jet are intensively studied because of their great potential for biomedical applications [1] The expansion of the jet at the exit of a capillary tube is of great interest for the application but the initiation and propagation of the ionisation wave all along the capillary tube determine the properties of the outgoing jet. This is one of the numerous applications of dielectric barrier discharges which requires a better understanding of the interaction between ionisation waves and dielectric surfaces, such as plasma/catalyst coupling for air treatment [2], air flow control by actuator [3], high pressure lamps ignition [4] or for avoiding flashover on insulating surfaces [5]. If the propagation of a streamer in the gas phase is relatively well known, the mechanisms involved in the interaction with a dielectric are still barely understood.

In the case of streamers guided inside a capillary tube, the confinement of the discharge is certainly important in the propagation mechanism of these "bullets", but several other parameters seem to be essential too. It appears from simulation that propagation can hardly occur over several tens of centimetres without a background electric field and/or an additional source of electrons to sustain the discharge. Like in any dielectric barrier discharge (DBD) configurations, the adsorbed charges have a key role for breakdown as well as for development of guided streamer inside capillary tube. Systems used for applications are all running with periodic power supply, most of the time with power supply frequency of few tens of kHz. As a consequence, guided streamers are propagating with already adsorbed charges all along the tube. These charges can either be a source of electrons, or just reinforce the electric field in front of the streamer head. However, the precise role of these charges has to be distinguished from the influence of the surrounding electrostatic field.

Discharges inside capillary tubes are usually initiated in a very small volume, for instance between two rings separated by few millimetres. This allows having an easy breakdown at relatively low voltage. However, when the guided streamer propagates far from the electrodes used to ignite the plasma, it propagates only because of its self-induced electric field. The discharge becomes then very sensitive to any modification of the surrounding, and especially to any metal part in the neighbourhood of the tube. In order to exhibit the role of a weak modification of applied electric field on the axis of the tube and the one of already adsorbed charges, experiments were performed in a coaxial geometry with different power supplies.

The reactor consists of a glass capillary tube of 1 mm inner diameter and 50 cm long with a dielectric thickness of 1.5 mm. The high voltage is applied between a pin of 20µm curvature radius at the entrance the glass tube and a grounded ring of 5 mm length stick to the outer surface of the tube 5 mm further. A gas flow of 10 to 200 sccm of He or Ar is used. The whole tube is kept at 25 cm from any metallic holder. In order to check the influence of electric field enhancement on the propagation, the capillary tube is surrounded by a large diameter grounded copper cylinder. The diameter of the cylinder is varied from 1.5 cm to 5 cm in order modify the distance between the capillary tube and the ground. A slot all along the copper cylinder allows performing fast imaging of the propagation. An

original design of isolated rings is also used with certain copper cylinders in order to perform current measurement all along the propagation without disturbing the discharge.
Three different power supplies are used to ignite the discharge. A 20 kHz sinusoidal power supply provides discharge with stable breakdown from one period to the next one. A 100 Hz power supply shows that discharge ignition becomes very unstable when streamers ignition is not repetitive enough. This can be due to a lack of remaining excited species or adsorbed charges on the wall. At least, a nanosecond pulser allows igniting single streamer in order to check the different behaviours when the propagation occurs in a tube without previously deposited charges.

The maximal length reached by the discharge as well as the velocity of the bullets is then measured by imaging and current measurements along the tube for the different diameter of copper cylinder as well as for two different pressures in the capillary tube (250 mbar and 1000 mbar).

The Fig 1 shows an example of light intensity along the propagation averaged over 300 half periods of the 100 Hz power supply. In this case the streamer ignited during the positive half period that means with the pin with positive high voltage appears to emit more intense light than streamers during the negative half period.

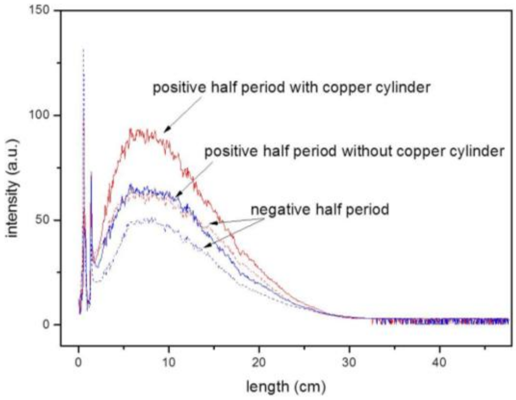

Fig. 1: Intensity of the light emitted all along the capillary tube averaged over 300 half-period of a 100 Hz sinusoidal power supply. The red curves are obtained with a grounded cylinder of 1,5 cm surrounding the 4mm diameter capillary tube.

It is also clear that for both polarities, the copper cylinder outside the capillary tube enhance the intensity of emitted light. The increase of the electrostatic field along the axis is very weak but during the propagation of the discharge, the streamer head brings the potential of the high voltage electrode closer to the grounded cylinder. The electric field forefront the streamer head is then significantly enhanced and modifies strongly the discharge properties.
These measurements shows clearly that none of the results obtained on guided streamer propagating inside capillary tube can be analysed without taking care of the surrounding material. For the application this can also means that somebody holding the pipe in which the bullets are propagating can possibly modifies the properties of the jet at the output of the pipe.

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