Properties of plasma bullets and the dynamics of the interaction of atmospheric pressure plasma jets with surfaces

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Cold atmospheric pressure plasma jets have been a subject of intense research in the last twenty years because of their potential in medicine, but also sterilization, synthesis, surface modification. A challenging but important property to measure is the electric charge in a single plasma bullet. This work discusses the use of Pockels' effect in such measurements and presents the results of charge measurements in different confitions.

Perhaps the most popular application area for non-thermal atmospheric pressure plasma jets is plasma medicine and disinfection of living tissue due to high-temperature chemistry exhibited in low gas temperatures, low transferred currents, in air at atmospheric pressure. For much of the same reasons they are likewise researched for their potential use in sterilization, synthesis and surface modification. In any case, the usage involves the presence of a substrate to be treated, often dielectric, not grounded, in the path of the gas effluent coming from the jet, but most of the research has been done on plasma jets freely expanding in room air.

Cold plasma jets have been investigated using a variety of feed gases, most commonly noble gases, but also air and noble gases mixed with oxygen for use in plasma medicine or with other admixtures depending on the final application. A wide range of excitation frequencies, voltage waveforms and geometries of plasma jets has been a subject of scientific research. Densities of reactive species in the effluent and the descriptions of discharge dynamics can be found for almost all combinations, while gas temperatures, flow dynamics, electron densities and electric field strengths can be found only in certain types of jets in a small number of publications [1-4].

Nevertheless, detailed knowledge about the charge carried by plasma bullets and the electric fields that characterize the plasma effluent is needed for better understanding of the processes in these discharges, the associated chemistry and the effect of the plasma on the treated surface in the final application.

The aim of this paper is to present and discuss the measurements of charge in plasma bullets formed in a helium kHz plasma jet.

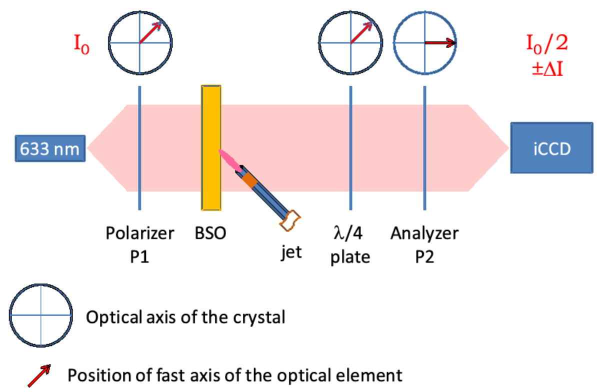

Figure 1: Schematic representation of the setup used for the measurement of electric field carried by plasma bullets.

The measurements were done on a setup similar to the one reported on in [2], and shown in Figure 1. The method is based on the Pockels' effect. Certain materials exhibit changes in optical properties in the presence of the electric field. In the case of the Pockels' effect, the changes in the refractive indices of the optical element are linear with the change in the applied electric field.

In the setup shown in Figure 1 a BSO ($Bi_{12}SiO_{20}$) crystal is used as the active optical element. The electric field caused by the plasma bullets arriving at 45° relative to the surface of the crystal induce a change in refractive indices of the crystal, which is detected as a change in the state of polarization of the monochromatic polarized light passing through

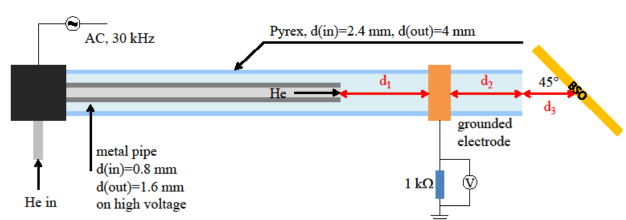

Figure 2: Schematic representation of the jet used in the measurements.

the crystal. An iCCD camera is used as a detector.

The jet used in the experiments has also been described in [2, 5] and shown in Figure 2. The geometry consists of a metal pipe that is simultaneously the gas inlet and the high voltage electrode, the Pyrex capillary 2.5 mm inner diameter and the grounded electrode on the outer side of the capillary. The length of the grounded electrode, the distance between the two electrodes and the length of the capillary are variable, as well as the distance between the end of the capillary and the BSO crystal. Helium is used at flow rates up to 1 SLM, sine excitation is applied at 30 kHz in a low-power mode (up to 1W dissipated in the discharge). The jet is run in the bullet mode where one plasma bullet is emitted per voltage period, without the presence of micro discharges around the grounded electrode. In addition to the measurements of electric field, the interaction of plasma and the dielectric target is observed by fast imaging techniques.

The Pockels' technique will be discussed, as well as translating the obtained signal into usable data. The results will show the relationship between the properties of plasma bullets and the applied voltage amplitude, gas flow, jet source geometry and the travelling length of the bullet. The results of fast imaging of the interaction of plasma bullets with a dielectric surface will be presented in addition. It will be shown that properties of plasma bullets are quite unaffected by changes in the applied voltage in the low-power range, while the dynamics on the dielectric surface depend strongly on the flow rate or angle of incidence.

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