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SIMULATION OF THE DISCHARGE PROPAGATION IN A CAPILLARY TUBE IN AIR AT ATMOSPHERIC PRESSURE

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In recent years, there has been an increasing interest for systems and processes using atmospheric pressure electrical discharges inside random or organized two-phase media such as porous solid, monoliths or foams. To understand and characterize the discharge dynamics in these complex media, as a first step we propose to study the discharge propagation in a capillary tube. The objective of this work is to study the influence of a radial geometrical constraint and of the value of the dielectric constant on the discharge dynamics in air at atmospheric pressure.
The studied configuration is shown on Fig. 1. A metallic point anode on a plane holder is set at 5 mm of a metallic cathode plane. The tip of the point is a semisphere with a radius of curvature r = 25 μm. The point is immersed in a capillary tube of inside radius r = 100 μm and outside

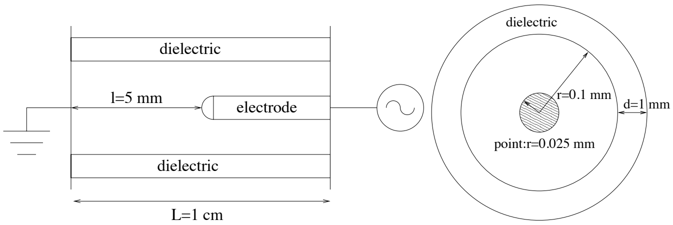

Fig. 1: Sideview and topview schematics of discharge set-up.

radius r = 1100 μm. A 2D fluid model is used to simulate the discharge propagation in the tube: continuity equations for charged species are coupled to Poisson's equation using cylindrical coordinates. First-order upwind scheme has been used for continuity equations and a direct solver MUMPS [1] for Poisson's equation. Transport parameters and source terms including photoionization are taken from [2]. On the dielectric interface, we considered secondary emission due to

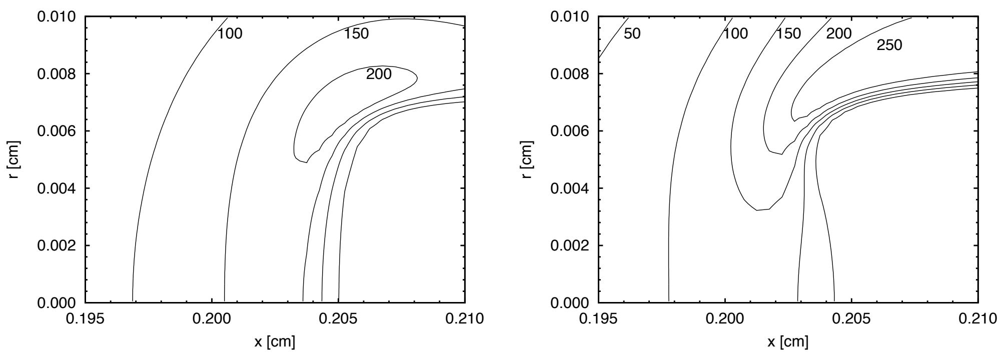

Fig. 2: Isocontours of total electric field when the discharge is at 0.2 cm from the cathode. Applied voltage: 6 kV, left figure: $\varepsilon = 1$, right figure: $\varepsilon = 5$. Contours vary from 50 kV/cm to 250 kV/cm.

condition	t [ns]	v [10^7cm/s]	max. E [kV/cm]	max. E_{axis} [kV/cm]
9kV, w/o diel	10.7	3.9	150	150
9kV, $\varepsilon = 1$	4.9	9.5	350	250
9kV, $\varepsilon = 5$	7.0	6.7	500	200
6kV, $\varepsilon = 1$	12.0	4.3	250	170
6kV, $\varepsilon = 5$	15.5	3.2	350	130
photoemission	6kV	$\varepsilon = 5$		
$k_{\text{ph}} = 5 \times 10^{-4}$	16.4	2.9	350	110
$k_{\text{ph}} = 5 \times 10^{-3}$	18.0	2.6	350	80

Tab. 1: Summary of simulation results. First column: applied voltage with dielectric parameters; Second column: propagation time until the impact on the cathode; Third column: average velocity between 2 and 4 mm from cathode; Fourth column: maximum total electric field in the gas volume; Fifth column: maximum total electric field on the axis of symmetry.

positive ion impact and photoemission [3]. On the metallic cathode, Neumann boundary conditions are used for species fluxes.

As an example of the results obtained, Fig. 2 shows at a given time, the spatial distribution of total electric field for two values of the dielectric constant of the tube: $\varepsilon = 1$ and 5. On both figures, the maximum of electric field is out of axis close to the dielectric. For $\varepsilon = 1$, the gradients of electric field are much more significant in the axial direction (the direction of propagation of the discharge) than in the radial direction. For $\varepsilon = 5$, significant gradients are observed in the radial direction. Tab. 1 summarized the most important results of this work. As a reference, we consider the case without dielectric tube for an applied voltage of 9 kV. With the tube, we note the discharge propagates faster. We note that the higher the permittivity, the lower is the discharge velocity. Same dependence is observed for an applied voltage of 6 kV and in surface barrier discharge [4] (fig. 11) and propagation of corona on a cylindrical insulating surface [5] (fig. 4). Tab. 1 also shows that the maximum electric field is increasing with increasing permittivity. However, if we compare the values of maximum total electric field and maximum electric field on the axis, our results seem to indicate that a faster propagation of the discharge is obtained when the discharge is more homogeneous radially in the tube. In the last two lines of Tab. 1 results including photoemission are shown for an applied voltage of 6 kV and $\varepsilon = 5$. As photoemission coefficients are not accurately known, we present results for two limiting values 5×10^{-4} and 5×10^{-3}. Photoemission processes produce free electrons at the dielectric surface and therefore help the discharge to propagate close to the surface. It is interesting to note that the discharge propagates slower for higher photoemission coefficient. Furthermore, Tab. 1 shows that a higher photoemission corresponds to a lower electric field on the axis. Then again, these results seem to show that a faster propagation of the discharge is obtained when the discharge is more homogeneous radially in the tube.

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