Numerical study of the influence of plane dielectric obstacles in the path of a streamer discharge in air at atmospheric pressure

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We present results on the effect of placing two thin dielectric layers in the path of a cathode directed streamer. We show how a positive discharge after its impact on a thin dielectric layer, ignites a second discharge behind the first dielectric plane. This second discharge propagates in the gap, impacts the second plane and reignite a third discharge behind the second dielectric plane. The influence of deposited surface charges on discharge dynamics and reignition is also discussed.

In recent years, there has been a growing interest for applications of atmospheric pressure discharges propagating inside random or organized two-phase media such as porous solid, monoliths or foams. To better understand discharge dynamics in these complex structures, as a first step, a study has been carried out on a discharge propagating inside a capillary dielectric tube ([1],[2]). In a second step, in this work, we propose to study the influence of dielectric obstacles on the discharge dynamics and in particular the reignition of the discharge behind these obstacles. The simulated electrode configuration is a point to plane geometry. A metallic hyperbolic point anode with a radius of curvature of 648μm (where $a = 0.5$ cm and $b = 0.18$ cm) is placed 5 mm from a metallic plane cathode. Between the electrodes, the right side of two dielectric layers are positioned respectively at 1.5 mm and 2.4 mm from the plane cathode. The two dielectric layers have the same characteristics: a thickness of 176μm and a relative permittivity of $\varepsilon_r = 5$. In this work, we assume that they are transparent to ionizing photons emitted by the discharge. A 2-D axisymetric code is used with drift-diffusion equations for charged species coupled with Poisson's equation in which we take into account contributions from volume charges and the charges deposited by the discharge on the surfaces of the two dielectric layers. These surface charges are obtained by time integrating charged particle fluxes to the different dielectric surfaces. At the dielectric surfaces, we have also considered secondary emission of electrons by ion bombardment (with a secondary emission coefficient of 0.1). Transport parameters and source terms with photoionization are taken from [3]. As initial condition, an uniform density of electrons and positive ions is considered (10^4 cm^{-3}) and a constant voltage of 13 kV is applied at the anode.
Figure 1 shows the isocontours of electron density at t=4 ns and t=5.7 ns. In the first 3.2 ns, a cathode directed streamer is ignited at the point electrode and propagates towards the right side of the first dielectric layer with an average field of 130 kV/cm and an electron density of 5.10^{13} cm^{-3} in the head of the streamer. At t=3.2 ns, the streamer reaches the first dielectric layer and its axial propagation is stopped. After the impact, the first discharge starts to propagate radially on the dielectric surface. At the time of the first impact, a high electric field ($\sim$ 90 kV/cm) is observed just on the left side of the first dielectric plane. During the first 3.2 ns, the electron density behind the first dielectric layer increases from 10^4 cm^{-3} to 10^9 cm^{-3} as the dielectric layer is transparent to ionizing photons emitted by the first streamer propagating toward the first dielectric layer. This rather high charged particle density with a high electric field at the time of the first impact leads to a fast reignition at t= 3.5 ns of a second positive streamer behind the first dielectric layer. On Fig.1, at t=4 ns, a high electron density of 10^{13} cm^{-3} is observed in the head of the second discharge propagating between the dielectric planes towards the cathode. It is interesting to note that during the propagation of the second discharge, the first one is spreading on the surface of the first dielectric layer and the discharge front is located at r=0.07 cm at

t=4 ns. During the first 4 ns, we also observed that the electron density has increased from 10^4 cm^{-3} to 10^9 cm^{-3} on the left side of the second dielectric plane ($x \leq 0.132$ cm) due to photoionization. The second discharge propagates in the gap from the first dielectric plane towards the cathode and impacts the second dielectric layer at t= 4.3 ns. At the time of the second impact, as observed for the first dielectric layer, a high charged species density and a high electric field are observed on the left side of the second dielectric plane which leads to a fast reignition of a third discharge at t= 4.8 ns. At t=5.7 ns, on Fig.1, we observe that during the propagation of the third discharge towards the plane cathode, the first discharge continues to spread on the first dielectric surface and the discharge front is located at r=0.14 cm at t=5.7 ns. The second discharge is also spreading on the surface of the second dielectric layer and its front is located at r=0.07 cm at 5.7 ns. The third positive streamer, with a high electron density of 10^{13} cm^{-3} in the head ($x \leq 0.132$ cm), (Fig.1) propagates from the second dielectric surface in the direction of the metallic cathode and impacts the cathode at 6.1 ns.

During the dynamics of successive propagations, impacts and reignitions, positive and negative surface charges are deposited on the right and left sides respectively of each of the two dielectric layers. During the first reignition process, the total amount of negative surface charges is higher than the positive one on the first dielectric layer. However, it is important to note that the amount of negative surface charges is very low and so it creates an electric field of only about ~ 1 kV/cm. Conversely, the electric field induced on the left side of the first dielectric plane by the first discharge after its propagation and during impact on the right side of the dielectric plane is much higher and is about ~ 90 kV/cm. We have observed the same results for the reignition of the third discharge behind the second dielectric plane. These results show that on the time scales studied in this work, surface charges deposited on dielectric surfaces have a negligible influence on the reignition of discharges behind the two thin dielectric planes.

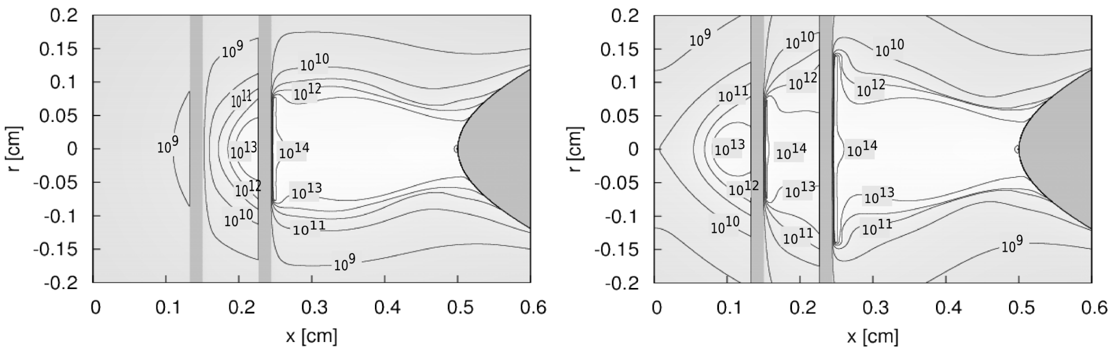

Fig. 1: 2D isocontours of the electron density at t= 4.0 ns (left) and t= 5.7 ns (right). Contours vary from 10^9 to 10^{14} cm^{-3}. Both dielectric planes have a thickness of 176μm and a relative permittivity of $\varepsilon_r = 5$

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