ANNEX 1

Three dimensional cold plasma modeling incorporating photoionisation phenomena

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INTRODUCTION

In this work a full three dimensional (3D) numerical model of a streamer in air at atmospheric pressure is presented. The electrodes' configuration is plane to plane and the gap distance 1 mm. Photoionisation radiation is taken into account via the solution of the two-exponential Helmholtz model with zero boundary conditions [1], [2]. The linearisation of the whole system of equations, continuity equations for charged species, the Poisson equation for the electric potential and the two Helmholtz equations for the photoionisation, is performed by Newton method and all the components converge simultaneously. The results are compared and validated by a two-dimensional (2D) axi-symmetric model as well as with different three dimensional approaches [3], [4].

GOVERNING EQUATIONS

The differential equations that describe the cold plasma are the Poisson equation for the electric field, the continuity equations for charged particles and the Helmholtz equation for photoionisation phenomenon:

$$-\vec{\nabla}\cdot\varepsilon\vec{\nabla}\Phi-\sum_j n_j q_j+\rho_S=0,$$

$$\frac{\partial N_e}{\partial t}+\vec{\nabla}\cdot(N_e\vec{W}_e)=aN_e\left|\vec{W}_e\right|-hN_e\left|\vec{W}_e\right|-b_{ep}N_eN_p+\vec{\nabla}\cdot(D_e\vec{\nabla}N_e)+S_{ph},$$

$$\frac{\partial N_i}{\partial t}+\vec{\nabla}\cdot(N_i\vec{W}_i)=aN_e\left|\vec{W}_e\right|-b_{ep}N_eN_p-b_{pn}N_pN_n+S_{ph},$$

$$\frac{\partial N_n}{\partial t}+\vec{\nabla}\cdot(N_n\vec{W}_n)=hN_e\left|\vec{W}_e\right|-b_{pn}N_pN_n,$$

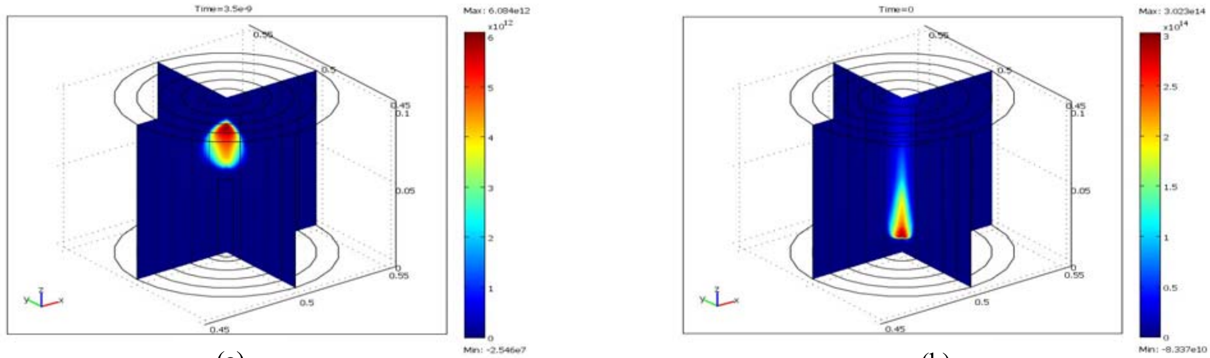
$$\nabla^2 S_{ph}^j-(l_j p_{O_2})^2 S_{ph}^j=-A_j p_{O_2}^2 I \quad j=1,2,3...,$$

where t is the time, N_e, N_p and N_n are the charge densities for electrons, positive ions and negative ions, $\vec{W}_e$, $\vec{W}_p$ and $\vec{W}_n$ are the drift velocities for electrons, positive ions and negative ions, respectively and D_e is the electron diffusion coefficient. The symbols α, η, β_{ep} and β_{np} denote the ionisation, attachment, electron–positive-ion recombination and negative-ion–positive-ion recombination coefficients, respectively. The term S_{ph} is the source term due to photo-ionisation.

RESULTS

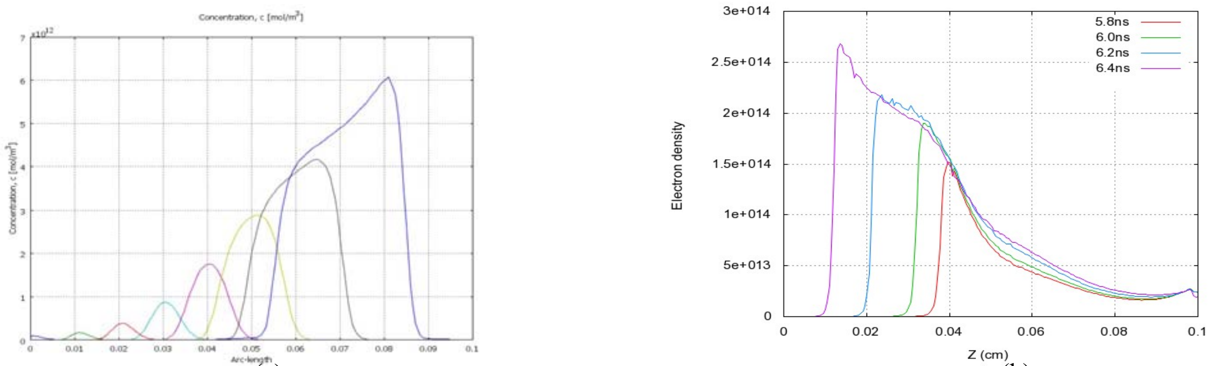
An initial Gaussian electron and positive ion density (plasma spot) are introduced in the gap at the cathode and the evolution of the gas discharge is simulated. Initially, the plasma spot is accelerated and multiplied via ionisation processes towards the anode, *Fig. 1(a)* and *Fig. 2(a).* On the anode the electrons are absorbed and gradually the conditions for the streamer formation are established. In *Fig. 1(b)* and *Fig. 2(b)* we see the electron density evolution during the streamer propagation.

During the streamer phase a shock ionisation wave propagates in the opposite direction of the electrons' drift velocity. It is very fast, about one order of magnitude faster of the electrons velocity; the gradients on its propagating front are very steep calling for special numerical techniques in order to reproduce it accurately. The passage of the streamer leaves behind a quasi-neutral plasma channel, a precursor stage for a plasma production.



(a) (b)

Fig. 1: Three dimensional electrons density evolution into the interelectrode space. Electron density during the avalanche phase (a), streamer propagation (b).



(a) (b)

Fig. 2: Electrons density evolution profiles in the axis of symmetry of the discharge. Electron density during the avalanche phase (a), streamer propagation (b).

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