Positive nanosecond surface discharge at high pressures and voltages

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Abstract: The aim of the present paper is to computationally study the morphology of surface streamers (filaments) at high pressures and positive applied voltages. The changes in discharge behavior with the increase of pressure and voltage are investigated with the goal to qualitatively explain some trends in the discharge behavior. The computational investigation is based on experimental data [1,2].

Keywords: Nanosecond discharges, high pressures, streamer-to-filament transition

1. Introduction

High pressure surface nanosecond pulsed discharges (nSDBDs) are frequently used for the stable and reproducible ignition of combustible mixtures [1,2]. As real combustion devices operate at pressures 10 - 20 bar it is necessary to study the morphology and behavior of nSDBDs at such high pressures. Recent experiments [1,2] investigated streamer-to-filament transition in the nSDBDs at pressures within the range of 1 to 10 bar. It was shown that high voltage nSDBDs at atmospheric pressure develops as a set of parallel plasma channels or streamers having the electron density 10^{15} cm^{3}. With the increase of pressure or applied voltage, a streamer-to-filament transition was observed. Typical times of the transition is 1-2 nanoseconds. After the transition, instead of the streamers bright thin luminous channels were formed having the electron density in excess of 10^{18} cm^{-3}. The diameter of these channels ("filaments" according to the notation [1,2]) did not exceed a few tens of microns. It was also shown that electron density increase was accompanied with dramatic changes in the discharge spectra while the intensity of the optical signal increased by a factor of 50.

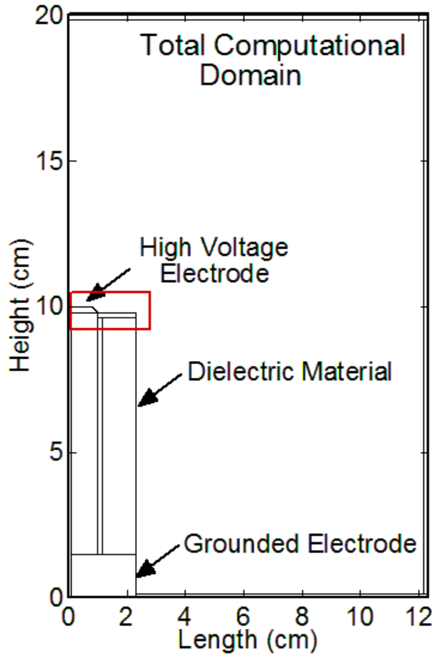

Fig. 1. Total computational domain used in the model.

2. Model

The aim of the present paper is to computationally study the morphology of surfaces streamers (or filaments) at high pressures and positive applied voltages and explore possible changes in the discharge behavior. The computational investigation is based on the experimental data [1,2]. The numerical model used in this investigation is *nonPDPSIM* whose algorithms are discussed in papers [3,4]. The 2D modelling platform *nonPDPSIM*, solves transport equations for charged and neutral species, Poisson's equation for the electric potential, the electron energy conservation equation for the electron temperature. The 2D geometry used in the model is shown in Fig. 1. The geometry is based on the experimental setup described in [2]. A metal disk 20 mm in diameter serves as a high voltage (HV) electrode. Close-up of the discharge region is shown in Fig. 2.

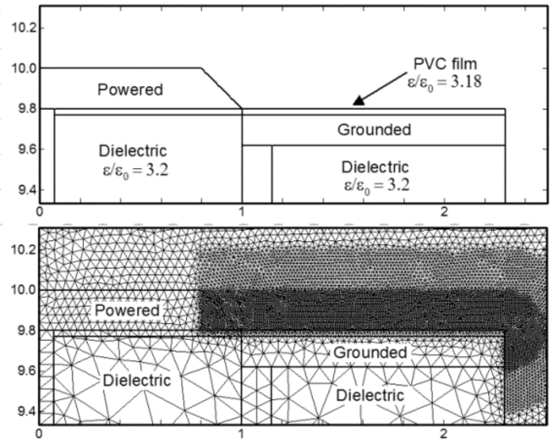

Fig. 2. Vicinity of the powered electrode (red box in Fig. 1) showing part of the computational domain with the unstructured mesh and several refinement zones.

The mesh is highly refined in the region where the surface streamer propagates. High voltage pulses (10-50 kV) of positive polarity, 20 ns in duration and 2.5 ns rise time are applied to the HV electrode. The discharge starts from the edge of the HV electrode and propagates radially above the surface of the PVC layer. The species included in the reaction mechanism are: electrons, N_2, $N_2(v)$, N_2^* ($A^3\Sigma$, $B^3\Pi$ and higher), N_2^{**} ($C^3\Pi$ and higher), N, N^*, N_2^+, N_4^+, O_2, O_3, $O_2(^1\Delta)$, $O_2(^1\Sigma)$, O, $O(^1D)$, O_2^+, O^+, O_2^-, O^-. The gas mixture is atmospheric-pressure air at 300 K. The high mesh resolution (< 1μm) near the exposed electrode and the dielectric surface is required to resolve filaments structure at high pressures. Positive filaments are launched by artificially having a small quasi-neutral cloud of seed electrons and ions (maximum density of 5×10^9 cm^{-3}) near the edge of the powered electrode.

3. Results and Discussion

Evolution of electron density for a streamer at 3 bar and 50 kV applied voltage is shown in Fig. 3. The maximum value of electron density exceeds 6×10^{16} cm^{-3}. It should be noted that such high density of electrons was also observed in experiments [2]. With the increase of pressure, the diameter of the filament becomes much smaller than the diameter of the streamer, as shown in Fig. 4. For example, at 3 bar and 50 kV, the diameter of the surface streamer ("measured" at the level of 10^{13} cm^{-3}) is 250-300 µm. With the increase of pressure up to 9 bar, the diameter reduces by a factor of 3. It does not exceed 100 µm (experiment [2] provides even smaller values).

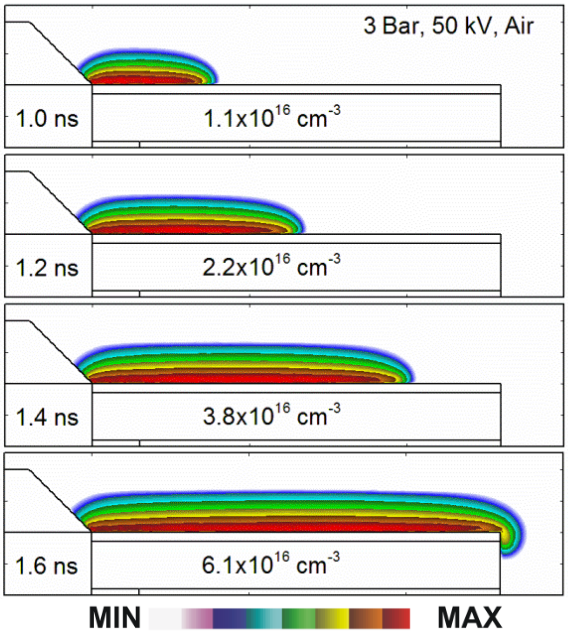

Fig. 3. Evolution of electron density (cm^{-3}) for a streamer at 3 bar and 50 kV applied voltage. Electron density is plotted within four decades log scale. The maximum value is noted in each frame.

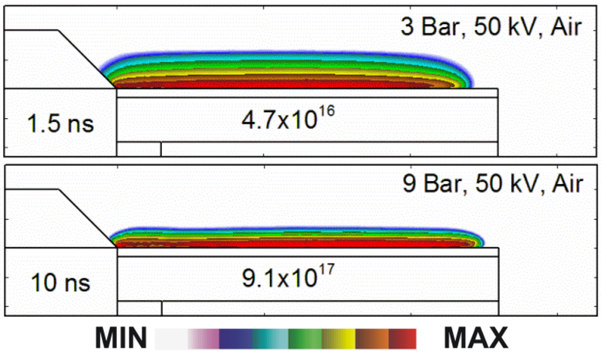

Fig. 4. Morphology of a streamer (filament) at 3 (upper frame) and 10 bar (lower frame). Electron density (cm^{-3}) is plotted within four decades log scale. The maximum value is noted in each frame.

The electron density increases up to 9×10^{17} cm^{-3}. It should be noted that extremely high electron densities (in the excess of 10^{18} cm^{-3}) with a long decay time were detected in experiments [1,2] for the discharge in the filamentary mode. As such, with the decrease of filament diameter there is an increase of the specific delivered energy into the filament. This fact, in particular, can explain the transition between the streamer and filamentary modes of the discharge. In the present simulation it was not possible to quantitatively distinguish between the streamer and filamentary modes of the discharge. It is partially due to the fact that with the 2D geometry, the discharge streamers (filaments) are perceived as infinite plasma layers while in experiments [1,2] the set of radial streamer channels is observed. In experiments [2] it was also shown that the pressure and voltage of the streamer-to-filament transition strongly depend on the oxygen concentration in N_2:O_2 mixtures. In the present work, the results from the computational study of the streamer morphology for different percentages of O_2 in N_2:O_2 mixtures will be also discussed.

4. Acknowledgement

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5. References

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