Numerical simulation of the interaction of two streamer discharges in air

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Interaction of streamers in air is studied via modeling analysis based on time and space adaptive algorithm with error control in Cartesian 2D geometry. Conditions under which two discharge filaments coalesce are identified and determined as a function of altitude, streamer polarity, electric field and configuration of initial seeds.

A numerical study is conducted in order to gain insight into an interesting, yet very complex phenomenon of the interaction of separate discharge filaments in air. Because of tremendous computational complexity of the problem in its generality, there exists only a few simulation works on this subject [1, 2, 3].

In this work, we are using a classical fluid model, considering drift-diffusion equations coupled self consistently with Poisson's equation [4, 5]. All the coefficients of the model are assumed to be functions of the local reduced electric field. Reaction rates and transport parameters for air are taken from [6]. Coefficients of diffusion of ions are based on Einstein relation. The photoionization source term is taken into account through the 3-Group SP_3 method derived by [7] with Larsen's boundary conditions proposed by [8].

We use an efficient numerical strategy, that was recently developed for multi-scale streamer discharge simulations. This strategy is based on a second order time adaptive integration and space adaptive multiresolution [9] for general Cartesian multi-dimensional geometries, and provides a time-space accuracy control of the solution. In this study we have chosen an accuracy tolerance of 10^{-4} to guarantee an accurate time-space representation of the physics. We have also tested that the results are qualitatively independent of the grid discretization and the size of the computation domain.

We study two separate discharge filaments initiated by placing two identical Gaussian plasma clouds into a homogeneous background electric field generated by two remote electrodes under various conditions. An example of characteristic interaction of two discharges of negative polarity is shown in Figure 1. Different phases of evolution of the net charge density of the discharge filaments are depicted for the ground pressure, a homogeneous external electric field of 48 kV/cm and the initial Gaussian seeds of width 0.02 cm with a maximum of 10^{13} cm^{-3} separated by a distance of 0.2 cm.

Conditions under which two discharge filaments coalesce are identified and determined as a function of altitude, streamer polarity, electric field and configuration of initial seeds.

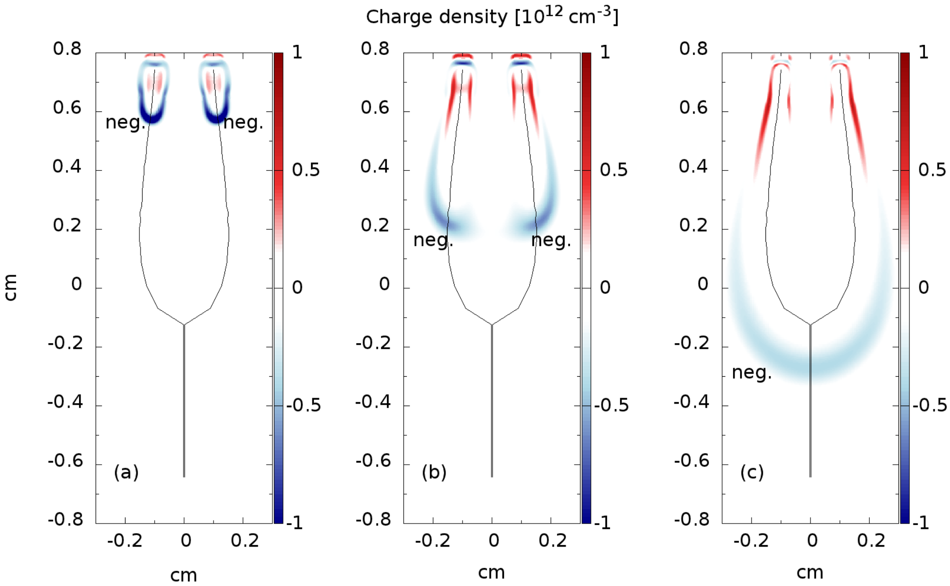

Fig. 1: Snapshots of different phases of evolution of the net charge density of two adjacent negative discharge filaments at ground pressure in air (sign of the charge in the discharge front is labeled), (a) 3.0 ns: two well developed streamers are repulsing each other, (b) 5.0 ns: the moment of transition between repulsion and merging, (c) 6.0 ns: after merging the discharge propagates through a single channel. Black solid line: complete trajectory of the maximum electric field.

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References

[1] G.V. Naidis, *J. Phys. D: Appl. Phys* **29** (1996) 779–783.
[2] A. Luque, U. Ebert and W. Hundsdorfer, *Physical Review Letters* **101** (2008) 075005.
[3] A. Luque, F. Brau, U. Ebert, *Physical Review E* **78** (2008) 016206.
[4] N.Y. Babaeva and G.V. Naidis, *J. Phys. D: Appl. Phys.* **29** (1996) 2423–2431.
[5] A. A. Kulikovsky, *Phys. Rev. E* **57** (1998) 7066–7074.
[6] R. Morrow and J. J. Lowke, *J. Phys. D: Appl. Phys.* **30** (1997) 614–627.
[7] A. Bourdon, V. P. Pasko, N. Y. Liu, S. Celestin, P. Segur, E. Marode, *Plasma Sources Sci. Technol.* **16** 3 (2007) 656–678.
[8] N. Y. Liu, S. Celestin, A. Bourdon, V. P. Pasko, P. Segur, E. Marode, *Appl. Phys. Lett* **91** 21 (2007) 211501.
[9] M. Duarte, Z. Bonaventura, M. Massot, A. Bourdon, S. Descombes, T. Dumont, *Journal of Computational Physics* **231** 3 (2012) 1002–1019.