Mechanism of establishment of electric streamer shape

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Streamers constitute an important stage in electric discharges in air, such as lightning. A propagating streamer has a columnar shape, consisting of an approximately hemispherical head and a channel behind it. The mechanism, by which the streamer "chooses" a certain radius of its head and other parameters of propagation, such as velocity, had been a long-standing puzzle. It is important to know these parameters accurately in order to understand, e.g., leader development and acceleration of electrons at the streamer tip with subsequent generation of x-rays.

Relations between streamer parameters may be written as algebraic equations. They produce a family of streamer-shaped solutions, with radius as a free parameter. We have hypothesized that all these solutions are, in fact, valid solutions of hydrodynamic equations, but the physical radius emerges when one solution is selected by the condition of being maximally unstable, i.e., having the highest velocity [1]. We shall refer to this solution as the "parametric model" of streamers.

The parameters of streamer propagation are determined by external conditions, namely the external electric field E_e (taken uniform in this study) and the streamer length L, which changes as the streamer propagates. In order to see how the streamer shape is established under constant external conditions, we use the following trick to fix L: we simulate a 'steady-state' streamer, such that its length is kept constant by synchronizing the motion of the electrode, to which it is attached, to the motion of the streamer head. The simulation is performed by numerically solving hydrodynamic equations on a grid with variable step size. We show that such a 'steady-state streamer' solution, shown in Figure 1(a,b), is close to the prediction of the parametric model, as demonstrated in Figure 1(c).

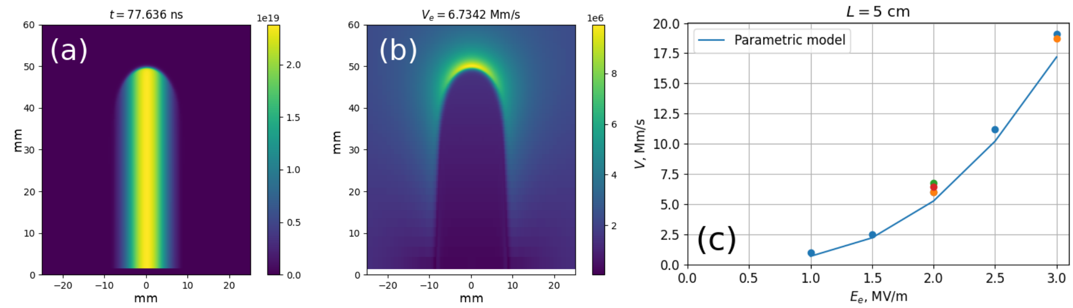

Figure 1. Results for $L = 5$ cm: (a,b) Steady state for external field $E_e = 2$ MV/m, with panel (a) showing electron density n_e, m^{-3} and panel (b), electric field E, V/m; (c) Velocity as a function of external electric field E_e. Solid line: parametric model, dots: results of hydrodynamic simulations, with various minimum grid steps.

We present results for both isolated streamers and groups of streamers propagating parallel to each other. For the latter case, a solution for an infinite streamer length is possible, and we may draw analogies to known solutions for a viscous Saffman-Taylor finger in a narrow channel [2].

The practical interest of this work lies in reducing the complexity of streamer propagation modeling. E.g., if the radius of the streamer head may be calculated quickly, we can avoid a detailed simulation of the streamer head.

References

[1] N. G. Lehtinen, "Electric streamers as a nonlinear instability: the model details," *submitted to Radiophysics and Quantum Electronics*, 2020, https://arxiv.org/abs/2003.09450.

[2] A. Luque, F. Brau, and U. Ebert, "Saffman-Taylor streamers: Mutual finger interaction in spark formation," *Phys. Rev. E*, **78**, 1, July 2008, pp. 016206, doi:10.1103/PhysRevE.78.016206.