On the spatial scale of streamers

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We calculate the streamer velocity, which is determined by the streamer mechanisms which include electron drift, electron diffusion and photoionization, in a 1D model that also includes the curvature of the ionization front. In particular, we show that the electron drift may contribute only to the propagation of negative streamers, and the effect of photoionization on the streamer velocity is mostly determined by the photoionization length. The results are used to modify the fractal model of [1]. The transverse size of streamers, as well as the fractal dimension of the streamer structure emerges from the front velocity dependence on electric field and the front curvature. In particular, when the photoionization is the main mechanism which determines the streamer propagation, the transverse size of the streamers is of the order of the photoionization length.

1. Introduction

Fractal nature of dielectric breakdown was investigated by [1] for the velocity of the ionization front (represented in their simulation as the growth probability P) $v \propto E^{\eta}$. They pointed out that in the case $\eta = 1$, the streamer growth is described by the same equations as the diffusion-limited aggregation (DLA) system which produces a branching fractal structure.

2. Streamer mechanisms

The following streamer mechanisms are added to the quasi-electrostatic (QES) equations written in 1D with the consideration of the curvature of the ionization front: (1) electron drift; (2) electron diffusion and (3) photoionization. The velocity of a propagating ionization front of fixed shape then is found to be in the interval $v > v_s$, where $v_s = 0$ when the streamer mechanisms are absent and $v_s > 0$ when one or more mechanisms are present. In particular, in the presence of photoionization only we find

$$v_s \approx \Lambda \nu_{max} f\left(\frac{\kappa\Lambda}{2}\right),\ f(q) = \sqrt{1+q^2} - q \qquad (1)$$

where Λ is the photoionization length and ν_{max} is the maximum net ionization rate. The dependence on curvature κ is through the function $f(q)$ which reduces the speed of a convex front.

3. Fractal simulations

We have modified the fractal model of [1] in order to include curvature according to function $f(q)$ given in equation (1). The result of a sample simulation is presented in Figure 1.

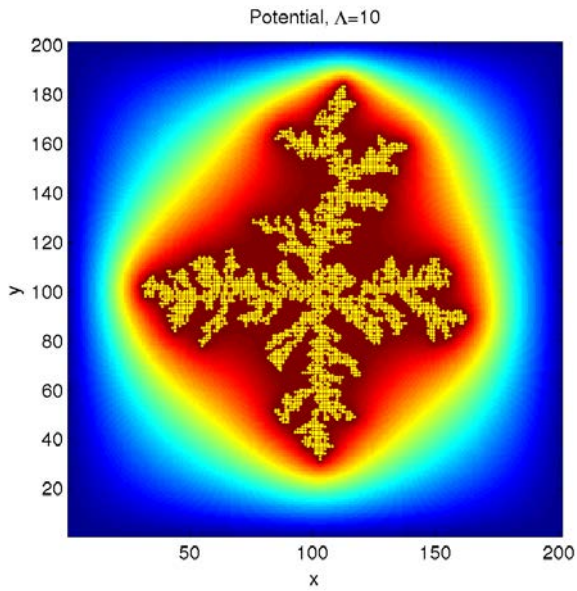

Figure 1. The fractal structures and electrostatic potential calculated for $\Lambda = 10$ (in the units of the grid step).

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5. References

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