Dynamics of Breakdown along a Dielectric Surface in Air at 1 atm

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1 Introduction

The dynamics of streamers over dielectric surfaces has been studied numerically by many authors, e.g. in [1] with a rectangular geometry using DC voltages, and in [2] with an axi-symmetric geometry using pulsed voltages. Various influencing factors on streamer dynamics are studied, like the applied voltage, the dielectric permittivity, secondary electron emission, the mobility of positive ions, distance of seeded streamer from dielectric surface, space charge on dielectric. Although their geometries are similar with qualitatively similar conclusions regarding the attraction of streamers to the dielectric surface, some conclusions differ regarding the role of secondary electron emission in increasing the surface streamer velocity, also the presented streamer dynamics show striking differences.

In this work streamers are generated in a weakly non-uniform electric field configuration in conditions of ~1% and more than 30% overvoltages as compared to the minimum breakdown voltage. The calculation of this minimum breakdown voltage is the topic of another contribution to this conference entitled 'Fast Calculation Tool for Breakdown Voltage in a setup with a Dielectric Surface'. The dynamics of streamer breakdown is studied under these conditions.

2 The Model

The studied setup has a 2D axi-symmetric geometry, in dry air at 1 atm, as shown in the figure. Numerical modeling was performed by solving transport equations for charged species, the Poisson equation and equations for photoionization source terms. The model is described in detail in previous work [3] and is, for these non-stationary calculations, supplemented on the dielectric surface by the boundary condition for charge accumulation,

$$\frac{\partial}{\partial t}(\varepsilon_D \boldsymbol{E}_D - \varepsilon_G \boldsymbol{E}_G) \cdot \boldsymbol{n} = \frac{\partial \sigma_s}{\partial t}$$

where subscripts *D/G* refer to Dielectric/Gas, ε is the dielectric permittivity, $\boldsymbol{E}$ the electric field, $\boldsymbol{n}$ the normal vector into the dielectric and $\sigma_s = \boldsymbol{j}_G \cdot \boldsymbol{n}$ is the normal current density. Initial conditions for the simulations at a certain DC voltage *U* were the 'no discharge' conditions, i.e. Laplace solution for the electric potential, homogeneous densities $n_{A^+} = 10^{10}$m^{-3} for positive ions and $n_\alpha = \frac{1}{4} n_{A^+}$ for electrons and three sorts of negative ions. For the initial surface charge over the dielectric, two initial distributions were studied, namely either zero surface charge (un-stressed setup), or the initial surface charge was that of the self-sustained

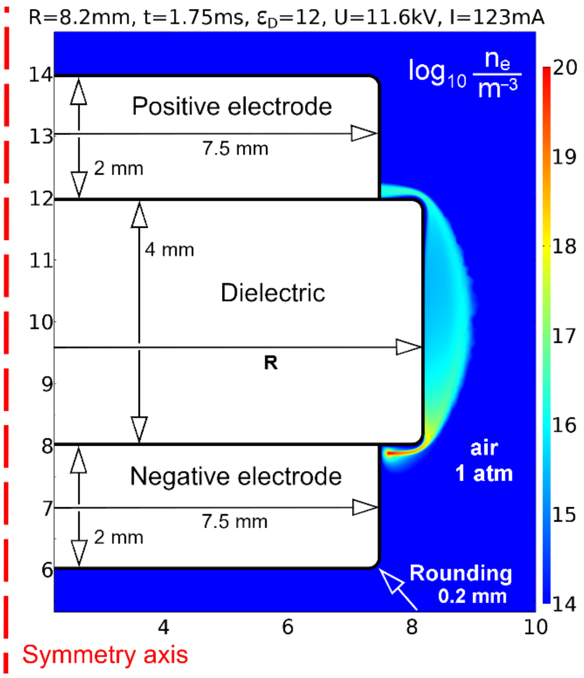


Figure 1: Schematic of setup. Logarithm of electron density just prior to breakdown for an overvoltage of 1%. Initial condition for surface charge was its distribution taken from the self-sustained discharge. Details in header of figure.

discharge, as calculated by the resonance method [3] with the boundary condition of zero current density across the dielectric surface (pre-stressed setup).

3 Results and Discussion

Three positions of the dielectric surface relative to the electrodes are studied: retracted (R=3mm); aligned (R=7.5mm) and protruding (R=8.2mm). The case of an 1% overvoltage, starting from a 'fresh' un-stressed setup, or from a pre-stressed setup (Figs. 1&2), resulted in a qualitatively similar breakdown dynamics. A streamer developed in the volume at a certain distance from the cathode as a result of a gradual space-charge increase. Breakdown would ensue in a few miliseconds. A noticeable exception was the un-stressed higher permittivity protruding dielectric, where breakdown through the streamer mechanism developed along fieldlines connecting cathode to dielectric in the very close vicinity of the cathode triple junction. For the initial condition of an un-stressed setup with a 1% overvoltage, only minor qualitative differences were observed in comparison with the pre-stressed case. For pre-stressed setups subject to higher overvoltages, Figs. 3&4 show an instant just before a streamer bridges the gap. In these cases positive streamers develop much faster, i.e. of the order of microseconds, and originate at the anode surface. As can be seen in Fig. 3 for the R=3mm case with a 30% overvoltage, after a positive streamer having traversed about half of the gap, another positive streamer originates in the volume in front of the cathode and closes the gap. In Fig. 4, for the case R=8.2mm, a positive streamer originated at the anode is seen 'hugging' the dielectric surface. This dynamics is more in accordance with the results reported in [1].

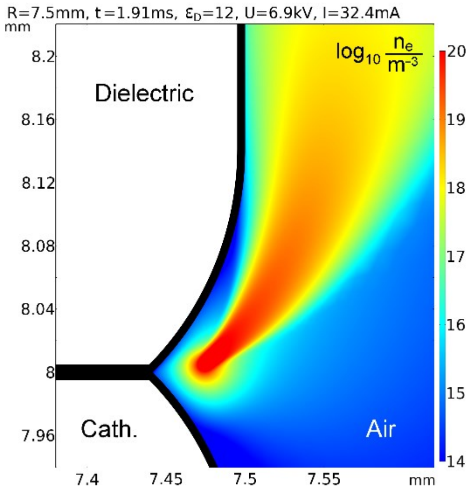
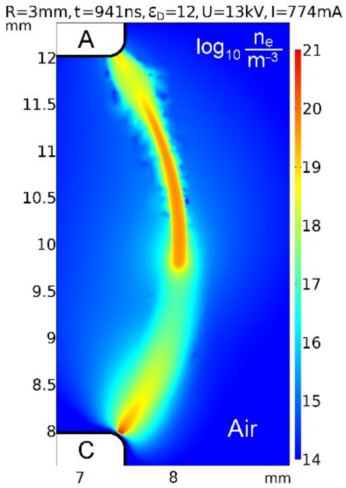


Figure 2: Logarithm of electron density just prior to breakdown for an overvoltage of 1%. Zoom of the cathode triple junction region. Details in header of figure.



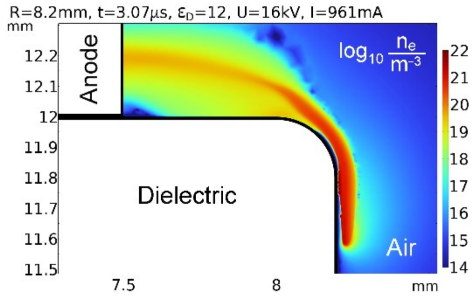


Figure 3&4: Logarithm of electron density just prior to breakdown for higher over-voltages. The case for R=3mm shows two streamers, one has developed in the volume close to the cathode. Above the case of R=8.2mm for an overvoltage of 38%. Details in headers of the figures.

This is an ongoing research, further simulations are planned for the higher overvoltages starting from an un-stressed setup. Future research will also clarify the effect, if any, of the effective secondary electron emission coefficient on streamer dynamics which in the present calculations was taken to be 3%.

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