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RANDOM DISTRIBUTION OF BACKGROUND CHARGE DENSITY FOR NUMERICAL SIMULATION OF DISCHARGE INCEPTION

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Introduction :

Inception and development of an ionizing front (streamer) in a gas may be obtained in inhomogeneous fields by accelerating the electrons of the cosmic rays ionization background, provided the gap voltage is above a threshold value depending on nature and pressure of the gas, and on geometrical configuration of the electrodes. In this study, we shall consider a point-to-plane configuration with 100 µm curvature radius for the anode point, the plane being grounded.

In dry air at atmospheric pressure, the average background density of charged particles is about 10^3 cm^{-3} and the discharge radius in the 150-200 µm range [1]. For a 1 cm gap, this allows a single electron to be present inside the volume defined by this geometry. This volume within which the discharge occurs will be, for simplicity, hereafter designed as *the tube*. As the streamers are initiated inside the active region located in the vicinity of the stressed electrode, the average number of electrons in this region is clearly less than one, and a model based on a uniform background may appear as not physical.

To avoid this, the background is modelled by a random density distribution with an average value about 10^3 cm^{-3} so that, after a time lag, one electron (or more) is certainly present in the grid cells close to the point electrode.

Averaging problems :

As, for a 150 µm discharge radius and 1 cm interelectrode gap, the volume of the tube is $V = \pi \times (150 \times 10^{-4})^2 \times 1 \approx 7.07 \times 10^{-4} \text{cm}^3$, one single electron (or ion) in the tube corresponds to a mean density of 1.41×10^3 cm^{-3} which, for simplicity, will be hereafter considered as the density of charged particles in the background. If now one considers a localization of this single particle within a few cells of the spatial grid, the averaging of density must be performed in space (along the discharge axis) *and* in time so that the mean number of particles at any instant is one for the whole tube.

One way to perform the spatial averaging in the case of a one-dimensional model is to consider for instance a 10^6 cm^{-3} density on 3 consecutive grid points, and zero at the other grid points. In the case of a 2000 cells uniform spatial mesh, one electron (or ion) is then surely present in the volume $\Delta V = \frac{3V}{2000} \approx 10^{-6} cm^3$, but it is the only one in the whole tube. These 3 consecutive points may be randomly chosen along the axis. Of course this is not fully realistic because ΔV is clearly much larger as the volume of a particle. However, it is small enough (when compared to the interelectrode gap) to locate the particule "somewhere" in the inhomogeneous field.

Time averaging is more tricky, because background particles may present various behaviours. For instance, a fast electron created by ionization of an atom by a hard γ-ray and crossing transversally the tube at a relativistic velocity spends only a few picoseconds inside and may be replaced (without changing the average density) as soon as it leaves the tube by an other one randomly located along the axis ; however, it can produce an avalanche. But this case is very unlikely : most part of the electrons are "slow" and when they enter the tube, they are captured by the field lines and derive towards the anode. The corresponding time is a few nanoseconds before they are absorbed at the point or by an incoming ionizing front if the discharge is already incepted. After this time lag, one can consider that the background electron has disappeared, and a new one may be found anywhere in the tube.

Physical and numerical model :

Thus, the initial background density of charged particles is modelled by a 10^6 cm^{-3} density randomly located over 3 grid points for electrons *and* positive ions, but the random position is different for each species. As a consequence, two cases must be considered. If the electron appears between the ion and the point, the electron will derive towards the anode, creating an avalanche and eventually a cathode directed streamer which will meet the positive distribution on his way. Inversely, if the ion is located between the electron and the point, recombination could occur before the development of an avalanche sufficiently important to create an ionizing front, but generally, in air, attachment will overbalance recombination.

The processes taken into account are ionization and attachment with dependence on reduced electric field adjusted from available data [2,3], and the hydrodynamic transport equations concern electrons, positive and negative ions. The numerical model, presented in previous papers [4-6] is a one-dimensional explicite finite-difference scheme, using the F.C.T method [7,8] with an amended version of Zalesak's flux limiter [9]. The electric field is computed by the classical "discs method" [10].

Results and comparisons with previous simulations :

Localization of the initial particle density allows to follow the avalanche growing and deriving towards the anode (Fig. 1) before leading to an ionizing front (Fig.2) propagating back to the cathode. This streamer inception is not very sensitive on the initial localization of the charged particles (comparison between Fig. 2a and 2b) but, as expected, the appearance of an

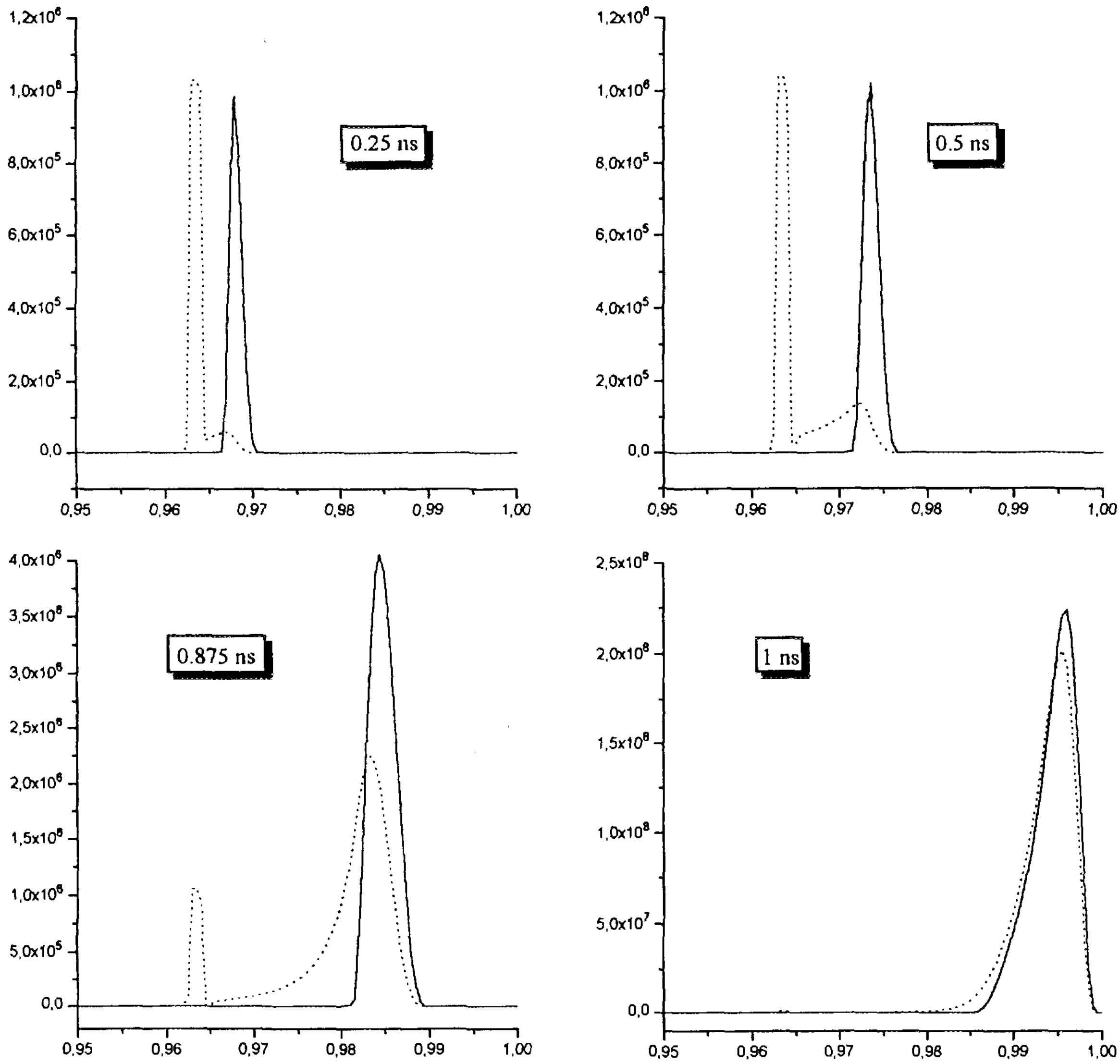
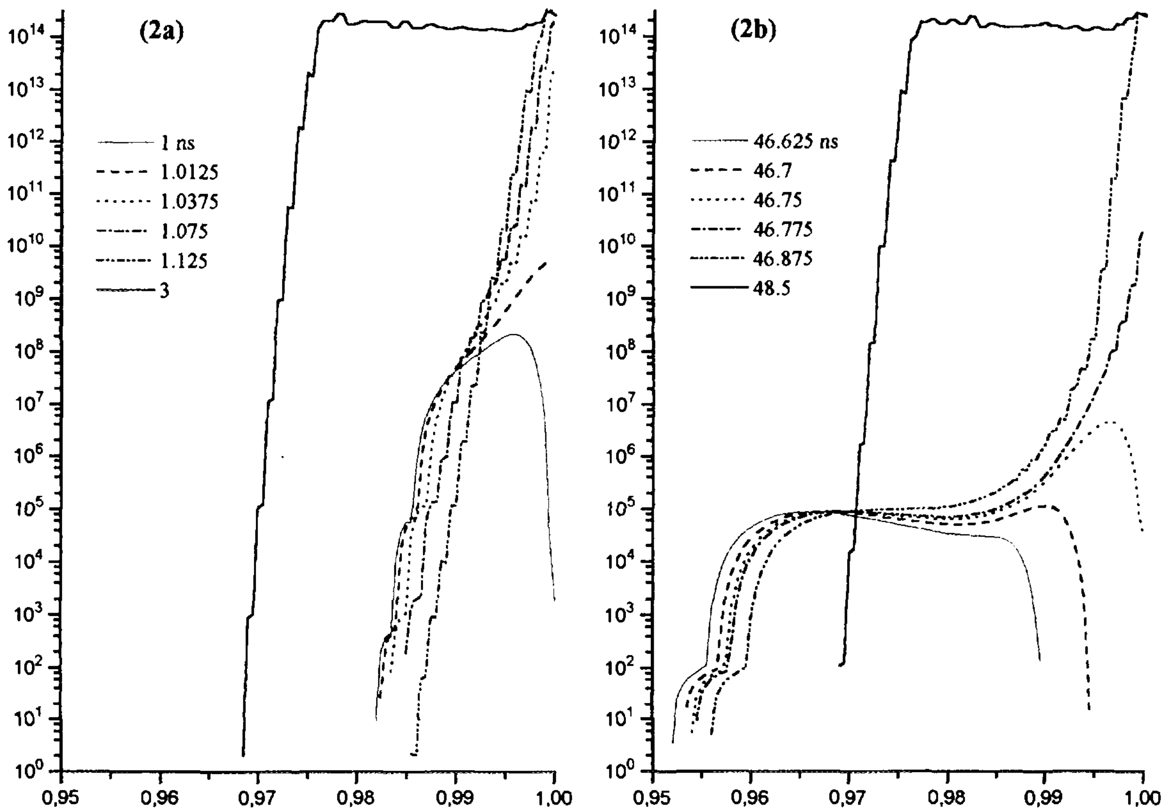


Figure 1 x-axis : distance from cathode in cm
y-axis : particule density in cm^{-3} (—— electrons ; ········ positive ions)
gap-voltage : 8.5 kV
initial position of electron and positive ion : X = 0.9645 cm



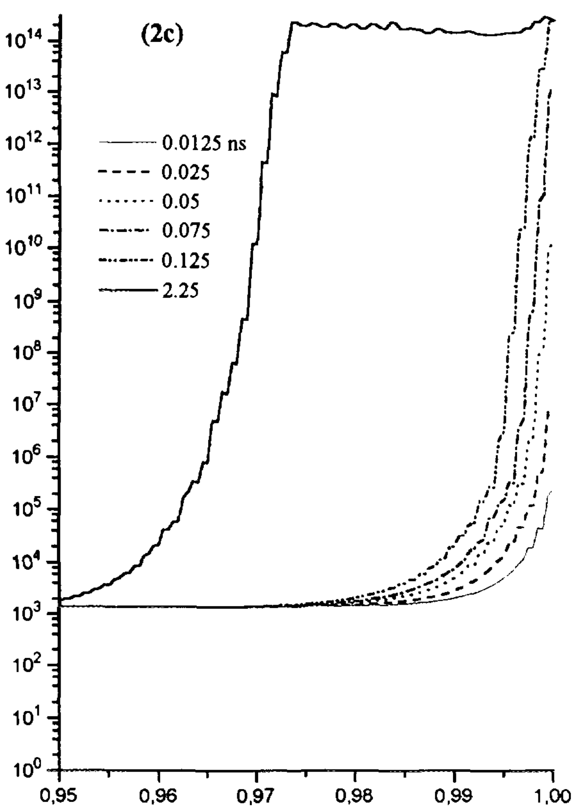


Figure 2

x-axis : distance from cathode in cm
y-axis : electron density in cm^{-3}

gap-voltage : 8.5 kV
initial position of electron and positive ion
- **(2a)** X = 0.9645 cm
- **(2b)** X = 0.7075 cm
- **(2c)** homogeneous distribution

ionizing front is delayed by several tens of nanoseconds if the electron has a long way to derive before reaching the anode, i.e. when its initial position is far from the point. Various computations showed that the initial localization of the positive ion is of negligible importance, so as its position relative to the electron.

Four main significant results of the simulations performed with this model can be noted :

(i) As the avalanche arrives in the vicinity of the anode, a modification of the electron density profile always occurs a few hundreds of μm before the point. This could be put in parallel with the "ionization distance" (related to the curvature radius of the stressed electrode) which would replace the interelectrode gap as characteristic length in the case of inhomogeneous fields [11].

(ii) As the initial background density corresponds to one electron (and one ion) in a volume ΔV, one particle is represented by the area beneath the initial ion density peak in linear coordinates and, with this unity, the growing number of particles in the avalanche can be evaluated (the result being reliable only when this number is much larger than one). An evaluation of the number of electrons present in the vicinity of the point when the avalanche turns into a streamer yields in all cases a value close to 10^8, which is the well-known Raether's criterion [12]

(iii) Comparison with the case of an uniform initial density of electrons and positive ions [5,6] (with $n_e = n_p = 1.41 \times 10^3\ cm^{-3}$) shows that the streamer inception is very similar (Fig. 2c), but the evolution and distorsion of the electron density profile is not displayed.

(iv) In all cases the value of the electron density in the streamer is uniform, and $n_e \approx 10^{14}\ cm^{-3}$.

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