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Study of the breakdown in a Plasma Focus like device

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Earlier investigations of breakdown in a Plasma Focus like device [3] show some differences between experimental data and modelling results. One of these is the earlier start time of breakdown predicted by the model. In present work we will focus our attention on initiation of the ionization processes in this device and we will explain the reason for the simulated earlier breakdown.

1. Introduction

The formation of a stable and homogeneous current layer is the main objective of Plasma Focus (PF) breakdown study. In the last year a significant step has been made in the breakdown modeling by the assumption that the photoelectrons appearing at the cathode may substantially support the development of the ionization process [1,2]. As a result an ionization wave sliding upon the cylindrical insulator surface was derived. The numerical results were experimentally confirmed with specially constructed mock-up device of the PF electrodes [3]. However the model does not explain some details in the experimental results. These are: the start time of the breakdown and the observed weak transverse traces between the upper horizontal cathode and the insulator surface at low pressures. It will be shown that the observed transverse traces could be numerically simulated if the start time of the breakdown is simulated correctly. The aim of current work is to present results of investigations of the breakdown start time in a device with PF like geometry.

2. Numerical Model

This study of the breakdown is based on a MC−FEM−PIC code that is well described in our previous works [1−3]. The geometry of the device is shown on Figure 1. The working gas is argon at pressure 10 mbar. The elementary processes that are taken into account are: elastic scattering [4], excitations to: $4s^1P_1$, $4s^3P_0$, $4s^3P_1$, $4s^3P_2$ states [5], excitation of one lumped 4p state [5], Penning ionization of $4s^3P_0$ [6] and $4s^3P_2$ [7].

Here it is also assumed that when an electron excites an Ar atom to resonance levels $4s^1P_1$ or $4s^3P_1$ this atom immediately emits one photon. This assumption is reasonable, because the life times of these levels are in the order of 2−3 ns.

The emitted photons from these excited states are with energy of the photons 11.83 eV and 11.61 eV respectively. In the calculations the coefficient for ejection of photoelectron is assumed to has constant value equal to $\gamma = 0.05$. Upon the generation of a photon a ray is generated in a random direction. The ray originates from the place where the excited atom was created. At the place where the ray crosses the cathode a new photo electron is created with probability γ. Here we neglect reabsorbtion and reemission of the photons from the neutral working gas.

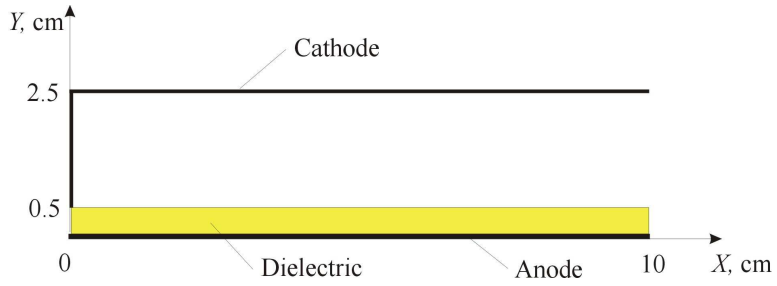

Figure 1. Schematic representation of a device with Plasma Focus like geometry.

3. Results and discussion

At the initial time moment, after external electric field is applied, there are few electrons in the device volume. These electrons (see Figure 3a) are slowly accelerated by the electric field, because in the beginning the electric field is very low.

The mean electron energy, shown of Figure 4, for the first 10-th nanoseconds is about 5−10 eV, which is under the threshold for ionization and excitation of the argon atoms. That is why only most energetic electrons are capable to ionize and excite argon. The voltage applied between the anode and the cathode rices with rate − 200 V ns^{-1} that is why the electric field rices with the same rate at each point of the device volume. Distribution of the electric field calculated up to 13-th nanosecond are very similar to the one shown on Figure 2, because the volume and surface charges at these times are not enough high to influence the external electric field.

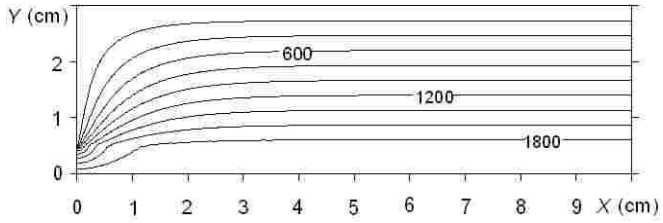

Figure 2. Distribution of the potential lines calculated up to 13-th nanosecond.

The figure shows that the potential lines are concentrated in a small area in the corner between the cathode and dielectric. In this region we expect to start the discharge.

Mean electron energy rices with growth of the electric field. At 10-th nanosecond (see Figure 4) the threshold energy for excitation is exceeded and a lot of excited atoms are created. At 11 ns few electrons appear in area where the electric field has most significant values, they are pointed with small arrows on Figure 3b and Figure 3c.

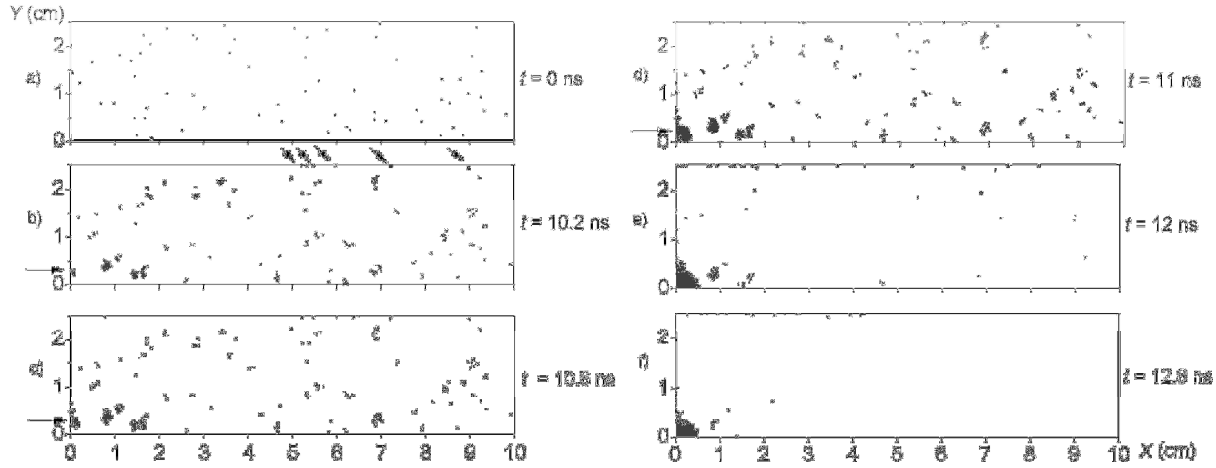

Figure 3. Single electron distribution in time interval 0−13 ns. Last two pictures show sample of 10^5 electrons.

Tracking of single electrons in the first several nanoseconds reveal that the photoelectron emission has essential role for creation of the initial electrons in device in area, where the electric field is very high. Later we will see that these initial electrons initiate the ionization wave sliding along the insulator surface.

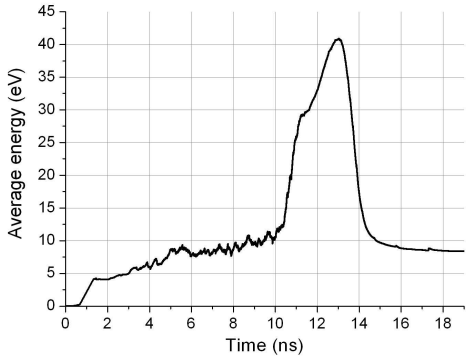

Figure 4. Average energy of all electrons in the device volume.

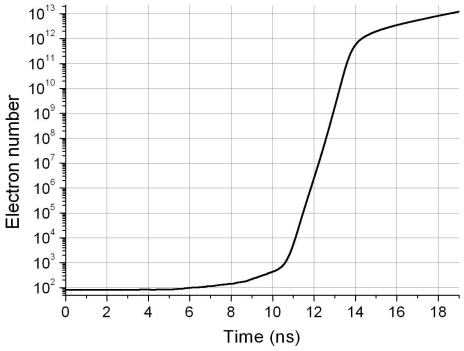

Figure 5. Number of all electrons in the device volume.

After the 11-th nanosecond the electrons created in the area with the high value of the electric field starts to create a lot of electron avalanches. Besides the created argon ions in the electron avalanches are created also a lot of exited argon atoms. The UV photons, emitted from the emission of excited atoms, eject photoelectrons from the cathode. These new photo electrons are created again in area where the electric filed has very high values. In that way a lot of chain reactions – electron multiplication and photoelectron ejection events are realized.

Now it is clear that the simulated earlier breakdown start time is due to earlier occurrence of photoelectrons in the corner between short part of the cathode and the dielectric. Thus the photoelectrical effect is responsible not only for sustain of ionization wave sliding along the dielectric surface [2,3], but also for the initiation of the ionization process. In the model the photoelectrons are ejected from photons born in the device volume. That is why in order to simulate correctly the breakdown start time we must use one more accurate model of the transport of these resonance photons from the inner part of the device to its walls.

For very short time period, from 11 to 13 ns, in this region are created large number of electrons (see Figure 3e and Figure 3f). On this figures is shown sample of 10000 electrons from all several tens of millions electrons. Electron density in the area between short arm of the cathode and the dielectric exceeds several times the density of the electron avalanche in the middle of device volume. That is why these avalanches can not be seen on Figure 3f. If we simulate correctly the transport of resonance emission than these small avalanches would be more intensive and would have more time to become larger and observable.

The intensive multiplication of the electrons before 13-th nanosecond can also be seen on the Figure 5 for the total number of electrons. The average electron energy also rapidly increases (see Figure 4) in this time interval, because a lot of electrons appear in the region where the electric field has very high values.

5. Conclusion

In present work we have studied the reason for the simulated earlier breakdown start time. It was show that if the transport of resonance emission is modelled in a more accurate way than the start time of the discharge will be simulated correctly. We also explained why the computer simulation can not reproduced the transverse discharges observed in the experiment [3]. It is remarkable to note that the photoelectrical effect is responsible not only for sustain of ionization wave sliding along the dielectric surface, but also for the initiation of the ionization process.

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