acta physica slovaca vol. 53 No. 6, 417 – 421 December 2003

INFLUENCE OF THE INSULATOR PARAMETERS ON DISCHARGE IN SMALL PLASMA FOCUS DEVICE *

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Received 3 April 2003 in final form 15 May 2003, accepted 28 July 2003

This paper presents a computer simulation of the electrical breakdown and influence of the insulator parameters (length, thickness, dielectric constant) on the discharge in a small Plasma Focus device. This model has been used to study the evolution of a discharge and especially its different character depending on the insulator parameters.

PACS: 52.58Rq, 52.80.Tn

1 Introduction

In the last years the Plasma Focus (PF) device has been grown with connection to new applications. The paper [1] presents the results of combined influence of X-ray radiation, high-energy hydrogen ions, high - temperature dense plasma streams and shock wave on the material irradiation. Cymer Inc. is proposing a concept for a 13.5 nm source based on dense plasma focus, as a source for extreme ultraviolet lithography [2]. A new idea to application is a possibility of the use of a dense plasma focus (DPF) device for the production of position emitting isotopes. In [3] calculations have been shown which demonstrate that a repetitive DPF device has a potential as a short-life-isotope breeder for medical applications and competes favorably with the presently used cyclotrons.

Quantitative evidence in terms of the neutron and X-ray output shows that successful sheath generation depends on the applied electric field, contamination, of the filling gas, electrode and insulator configuration. The thickness and length of the insulator exert an influence on the electrical field line distribution and on the character of the breakdown. An uniform breakdown and formation of well defined current sheath are of fundamental importance in neutron production. For a small PF device, this dependence is straightly evidence.

Many authors [4], [5] have investigated the mechanism of the breakdown and the influence of the electrode-separating insulator on the discharge in the PF device. The initial stage of the discharge in PF devices is still a matter of an experimental research due to importance of this phase for dense plasma pinch formation [6]. Interferometric and spectroscopic measurements performed near the insulator and in the run-down region show residual plasma densities which amount up to 30% of the initial filling density after the plasma sheet has left these regions [7].

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[*] Presented at XIVth Symposium on Application of Plasma Processes, Liptovský Mikuláš (Slovakia), January 2003.
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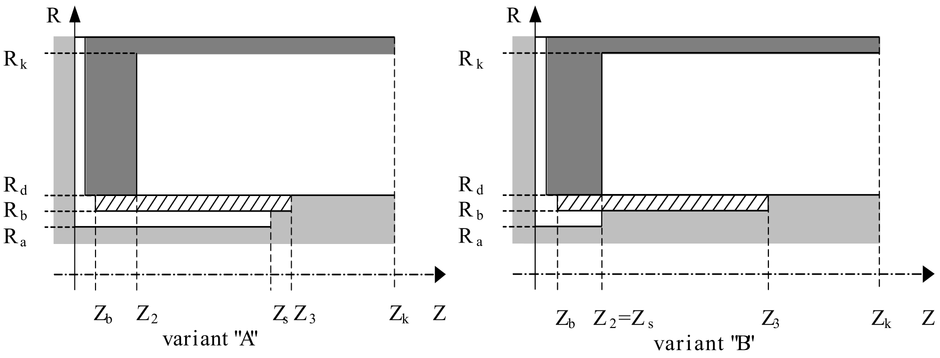

Fig. 1. Schematic presentation of two variant insulator-electrode system for Plasma Focus.

Theoretical studies - computer simulation and modeling of the electrical breakdown phase in the coaxial electrode system, known as Plasma Focus which are especially related to PF-1000 facility are presented in [8], an effect of the insulator dielectric constant on the breakdown is presented in [9] and the evolution of a discharge and its different character depending on the applied gas pressure is demonstrated in [10].

This paper presents a computer simulation of the electrical breakdown phase in a coaxial electrode system of the small PF device, which is designed and will be operated at the IPPLM in Warsaw. This model has been used to study the evolution of a discharge and especially its different character depending on the insulator parameters. This device will be equipped with the Mather type insulator-electrodes system of following parameters: the radius of the inner and outer electrode are $R_a = 0.022$ m, $R_d = 0.03$ m. The cylindrical insulator embraces the central electrode. The insulator is put together with two type of cylinders. The first was made of teflon and second one which was embeded on the first is made of the alundum (Al_2O_3). The schematic presentation of the PF device with two different parameters of teflon insulator: variant “A” Z_s(length of the insulator made of teflon) = 0.09 m and variant “B” with Z_s = 0.024 m is shown in Fig. 1. The length of the insulator made of alundum is the same in two variants.

2 The model

The main problem in describing the electrical breakdown formation is to analyze the behavior of charged particles in the electric field. In our case to describre their behavior it is convenient to use the conservation equations. The general form of the conservation equation for electron and ions is following:

$$\frac{\partial n_{e,i}}{\partial t} + \nabla.(n_{e,i}\overrightarrow{V_{e,i}}) = Q^{+}_{e,i} + Q^{-}_{e,i}, \tag{1}$$

where $n_{e,i}$ is the number density of particles, vector $\overrightarrow{V_{e,i}}$ is the drift velocity, $Q^{+}_{e,i}$ is the number of particles produced per unit volume and time, and $Q^{-}_{e,i}$ is the number of particles lost. The subscripts e, i refer to electrons and ions, respectively.

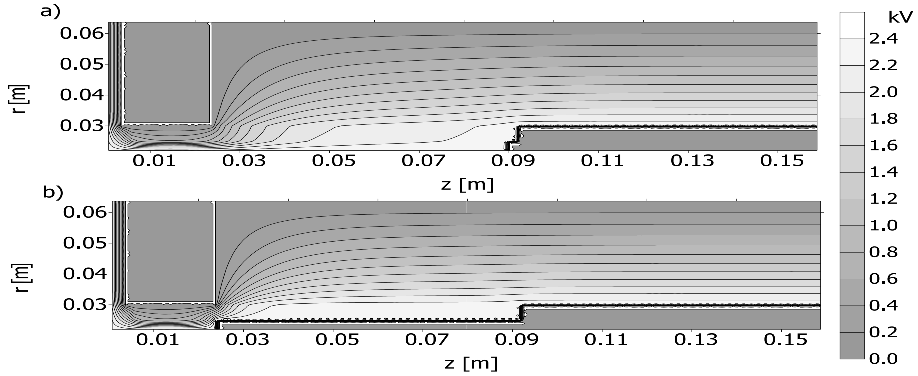

Fig. 2. Simulations of the equipotential lines for a electrical potential for variant "A" (a) and for variant "B" (b) at the time 11.8ns.

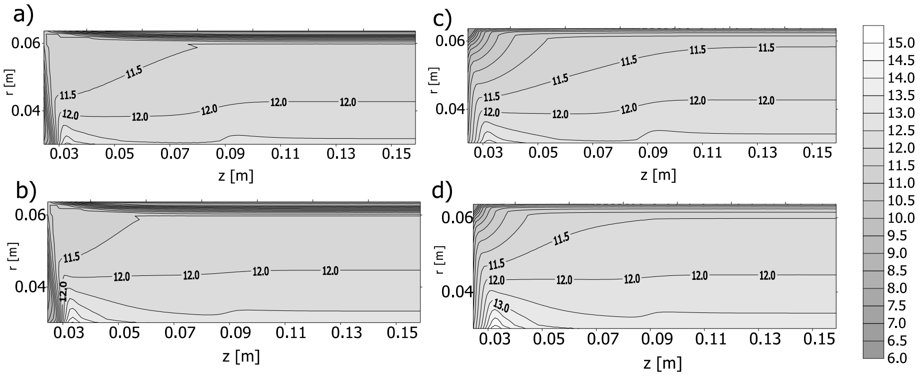

Fig. 3. The electron density (a, b), ion density (c, d) at the time t = 11,8 ns for the variant "A" (a, c) and for the variant "B" (b,d).

As it was mentioned above the set of conservation equations is coupled with the Maxwell equations, which can be reduced to the Poisson equation, when potential component of the electric field is larger then rotational component of the electric field. To solve the above equations it is necessary to specify the boundary conditions at the electrodes and insulator surface. We assume that the electrons emitted from the cathode are the effects of the incidence of positive ions. The coefficient of the probability of the electron emission per incident ion is $\gamma_i = 0.15$, which is in reasonable agreement with the experimental data.

We found that it is necessary to choose the Flux-Corrected Transport (FCT) method [11]. Our algorithm extends the work presented by Mc Donald et. al. [12].

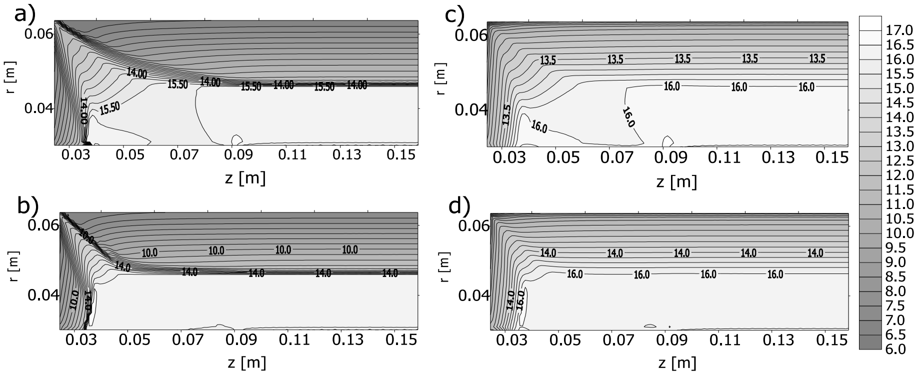

Fig. 4. The electron (a, b) and ion (c, d) density for variant “A” (a,c) and for variant “B” (b, d) at the time t = 24,61 ns.

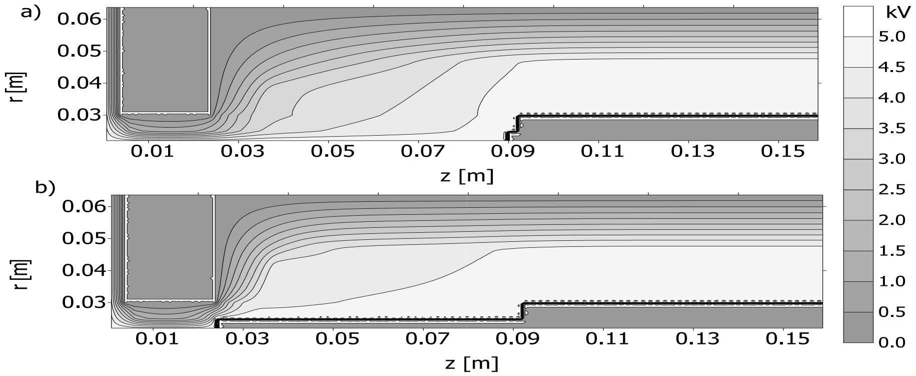

Fig. 5. Simulations of the equipotential line for electrical potential for variant “A” (a) and for variant “B” (b) at the time $t = 24.61ns$.

3 Results and discussion

The calculations have been made to simulate the set up presented in Fig. 1, with the following parameters: hydrogen pressure p = 400 Pa, maximum charging voltage U_{max} = 35 kV, voltage rise $dU/dt = 2.10^{11}$ V/s, uniform initial electron and ion density of 10^{10} m^{-3} in the whole discharge space, dielectric constant values ε_1 = 2, ε_2 = 8 for teflon and alundum, respectively.

The equipotential lines of the electric field for two insulator variants “A” and “B” are presented in Fig. 2. for the time 11.8 ns. Comparring two variants, we can see that for the variant ”B” we have a sharp gradient nearly the cathode. This disposition of electric field exert an influence on the ionization and density for charge density (electron and ion).

Fig. 3 presents the electron density (a, b) and ion density (c, d) at the time t = 11,8 ns for the variant “A” (a, c) and for the variant “B” (b, d). If the value on the contour of constant densities is 12.0, the real electron density is 10^{12} m^{-3} and so forth. The numerical simulations show that the electric field is not significantly distorted by space-charge in the early stage of an avalanche.

We see that ionization is growing faster for the variant “B”, i.e. the electron and ion densities are increasing faster.

The electron and ion densities at the time $t = 24.61$ ns are presented in Fig. 4. We observe two different characters of the discharge: for variant “A” there are two point in which the density increases, the first near the cathode and the second one nearly the insulator/anode border. We observed gliding discharge for this case. For variant “B”, we have one point in which the density increases. This point is situated near the cathode.

At this time instant, the electric fields have been significantly distorted by the space-charge (see Fig. 5).

4 Conclusion

The numerical calculations have shown that the place where the streamer is formed depends on the intensity of the electrical field, that exists between the electrodes and on construction of the insulator. When the shorter insulator made of teflon is used, the initial electrons drift farther from the cathode, and the ionization wave is formed closer to the cathode, so that the streamer can be formed only near the cathode, there is no streamer near the insulator/anode border. When the longer insulator made of teflon is used, the ionization wave is formed in two point.

The results present different discharge phases for insulators of different lengths. From our calculations it follows that an uniform breakdown and formation of well defined current sheath will occur in variant “B”.

Acknowledgement: This work has been supported by the IAEA CPR grants No. 11940, 11941.

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