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COMPUTER MODELING MICRODISCHARGES BETWEEN ELECTRODES COVERED BY DIELECTRIC

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Abstract. In this paper, we are modeling the breakdown phenomena in barrier discharge. A two dimensional model consists of the Poisson equation and the conservation equations for electrons and ions, using drift diffusion and local approximation. The model is applied to a gap between the dielectric filled up with helium gas at atmospheric pressure by specific initial conditions.

Keywords: computer modeling, microdischarges, breakdown, streamer.

INTRODUCTION

Transient gas discharges, known as micro- or barrier discharges, occur at atmospheric pressure between electrodes, where at least one electrode is covered by a dielectric barrier.

The experimental and theoretical studies of the atmospheric pressure discharges have been motivated by numerous applications for the plasma processing of materials including the thin-film production, the reduction of thin oxide layers, ozone formations, etc.

These discharges consist generally of a large number of short-lived parallel filaments, also called microdischarges. The formation of microdischarges has been discussed by number of authors [1,2]. In paper [1] it was shown that a mechanism responsible for formation of the microdischarge filaments has been identified as the steamer mechanism.

Two approaches are popular for modeling of streamers: the Monte Carlo method and self-consistent fluid model. In [3], authors compared the results of the fluid models with those obtained using Monte Carlo method to test the validity of model for a description of the streamers development under the conditions investigated. They have found that the results from the non-equilibrium fluid model is closer to that of the Monte Carlo method, but the fluid model requires significantly less computer time than the Monte Carlo method.

In present paper, we use a two dimensional fluid model to simulate the breakdown phenomena in a barrier discharge. The results of the simulation present different discharge phases, a homogenous and a space-charge dominated phase, a phase with field enhancement due to positive ions causing streamer formation.

THEORETICAL MODEL

The two dimensional model consists of: the Poisson equation (1) and conservation equations for electrons, ions, and excited particles (2)-(4). We take into consideration the effects of direct ionization, as well the effect of Penning and stepwise ionization, because the rate of the primary ionization of a rare gas by electron impact becomes very small at E/N, and the second ionization processes can significantly contribute to the ionization [4].

$$\nabla^2\Psi = -4\pi e(n_i - n_e) \tag{1}$$

$$\frac{\partial n_e}{\partial t} + div(n_e \vec{V_e}) = \alpha n_e V_e + K_{e*} n_e n_* + K_{im} n_{im} n_* \tag{2}$$

$$\frac{\partial n_i}{\partial t} + div(n_i \vec{V_i}) = \alpha n_e V_e + K_{e*} n_e n_* + K_{im} n_{im} n_* \tag{3}$$

$$\frac{\partial n_*}{\partial t} = \beta n_e V_e - K_{e*} n_e n_* - K_{im} n_{im} n_* - K_{2m} n_* N_0^2 - \frac{n_*}{t_*} \tag{4}$$

where Ψ is the electrical potential, n is the number density of particles, vector V is the drift velocity, α is primary ionization coefficient, β is the excitation coefficient, K_{e*} is coefficient of the stepwise ionization, K_{im} is ionization coefficient read over Penning ionization, K_{2m} represents the metastable atom-metastable molecule conversion and t_* is the lifetime of an excited atom. The subscripts e, i and * refer to electrons, ions and excited atoms, respectively.

The model is based on assumption of low degree of ionization, so that the transport coefficients of the gas are uniquely determinate by the local electric field.

The electron mobility is *987* cm^2/Vs, the ionization and excitation coefficient are taken from Novak and Bartnikas [5]. In Ref. [5], the authors present analyze and analytical approximation for those coefficients. A rough estimate of the relative density is 10^{-4}, and impurity species are N_2, O_2, CO_2 and H_2.

The continuity equations (2)-(4) are solved numerically together with the Poisson equation (1) using a finite difference technique. A major difficulty encountered here is that of the accurate simulation of the evolution of densities with very steep gradients and value changing of order of magnitude. Because the ionization caused by the electrons is strongly dependent on electrical field, considerable care should be taken to find an optimum numerical scheme for nonuniform fields.

We found it necessary to choose the Flux-Corrected Transport (FCT) method [6] and flux-limiting algorithm, described by Zalesak [7].

To solve the equations it is necessary to specify the boundary conditions at the dielectric, including the effect of surface change build-up on the insulator surface. Exactly describe of the this boundary condition and model are performs in [8]. In paper [8.9] we numerical study on the evolution of the microdischarges and strimer formation between electrodes covered by dielectric in dependence from voltage rise.

The main goal of the paper is to understand and describe the phenomena of the electrical breakdown and mechanizm on streamer formation in barrier discharge under specific initial condition.

EXPERIMENTAL SETUP AND RESULT

We consider a gap of 1 mm between two insulator layers with dielectric constant $\varepsilon = 2$. Calculations have been made for the following parameters: helium pressure $p = 760\ Torr$, max charging voltage $U_{max} = 10\ kV$, voltage rise $dU/dt=1.10^{10}\ kV/s$, the initial electron density is 10^2 cm^{-3} in discharge space and initial electron density from dielectric surface is 10^5 cm^{-3} in select cell (three group of three cel). Schematic representation of the experimental setup is shown in Fig.1.

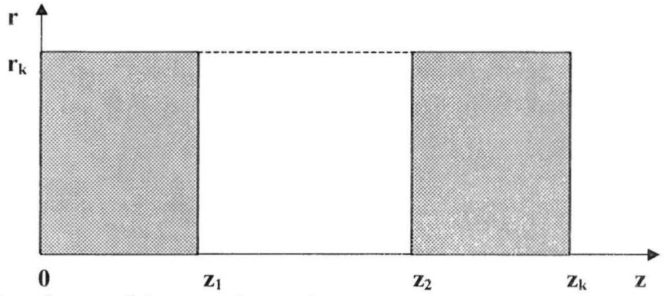

Fig. 1. Simple scheme of the experimental setup.

The calculated 2-D electron and ion density profiles are presented by the contours densities in (r, z) space. The scale in this figure is logarithmic. If the value on the contour of constant densities is 4.0, the real electron density is $10^4\ cm^{-3}$ and so forth.

In the early stage of an avalanche, the numerical simulations shown that the electron clouds grow and propagate only toward the anode, and the electric fields have not significantly distorted by space-charge. This phase is presented in Fig.2.

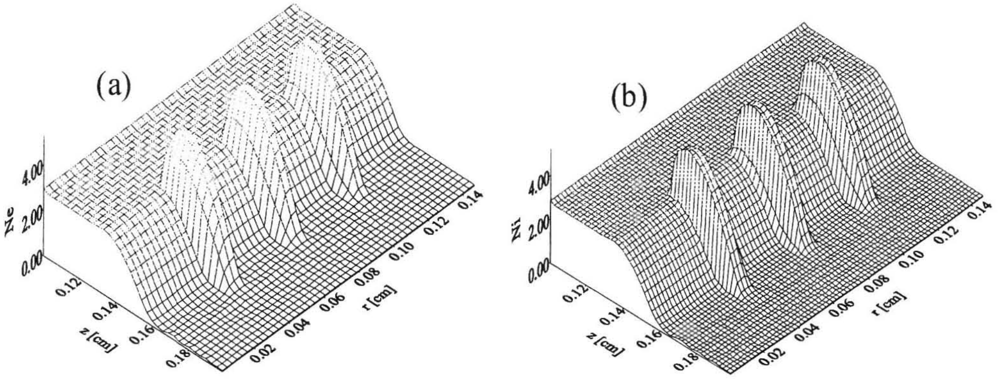

Fig. 2. Simulations of equipotential lines of electron (a) and ion (b) density for time t = 47.4 ns.

The evolution of the electron density distribution in the radial direction is the same as in longitudinal direction (z direction). It is determined by the ionization and radial electron migration. In the early stage of the avalanche (for time smaller than *48 ns*, the numerical simulations show that the clouds grow and propagate only toward the anode, and electric fields have not been significantly distorted by space-charge.

In the time, where the electron density is larger of $10^{10}\ cm^{-3}$ internal electric field, which is generated from space-charge, begin significant. This phase is presented in Fig.3.

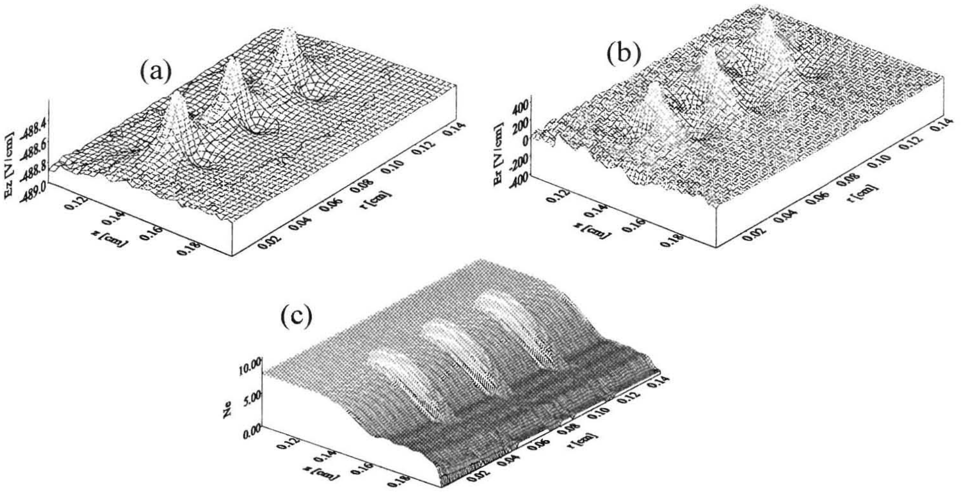

Fig.3. Simulations of equipotential lines of the longitudinal (a), radial (b) electric field and electron (c) density for time t = 48.9 ns.

The electrical field in the radial direction is lower and it changes more smoothly than that in the longitudinal direction. The electron density expansion in radial direction is slow, but in the time with increase the space-charge, the difference lower. Evolution of the longitudinal and transversal electric field is presented in Fig. 4 at the time t = 48.95ns.

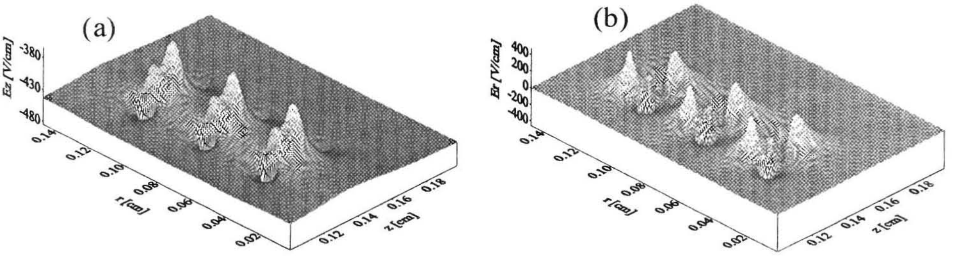

Fig. 4. Simulation of equipotential lines of the longitudinal (a) and radial (b) electric field at the time t=48.95ns.

In the Fig. 5 is shown stage, where three anode and cathode streamers were formatted. The space-charges is large. We observed changes in equipotential lines for electric potential (Fig. 5e). We observed that electron and ion density grow in radial directional.

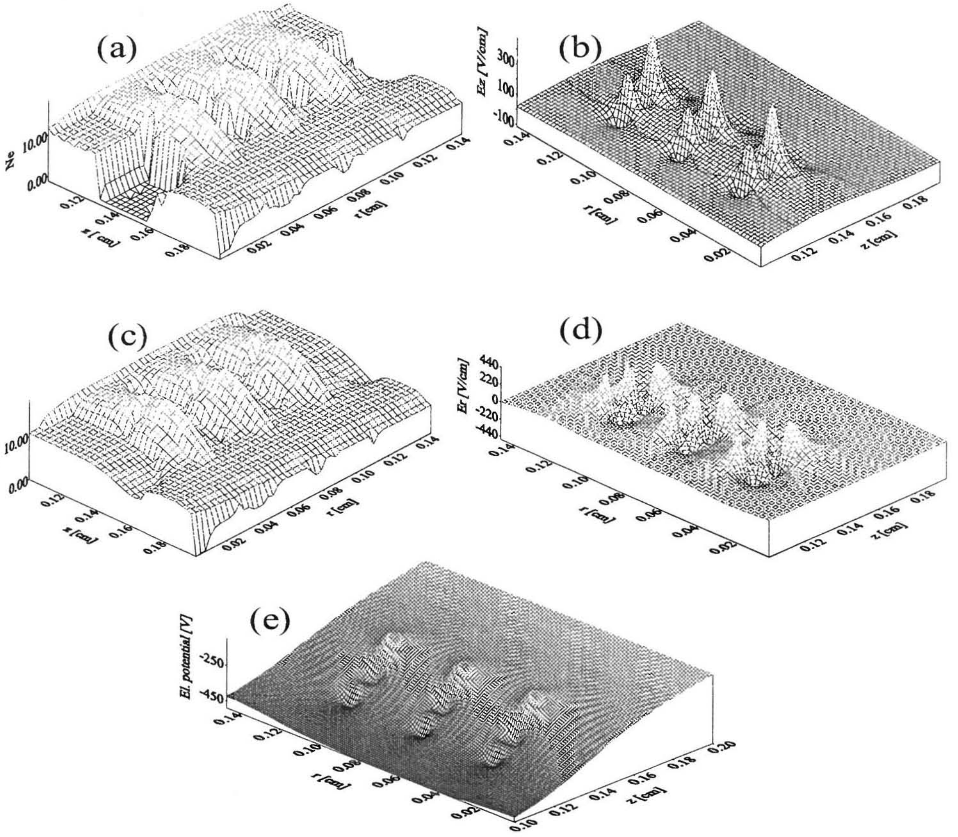

Fig. 5. Simulations of equipotential lines of electron density (a), longitudinal electric field (b), ion density (c), radial electric field (d), electric potential for time t = 48.9 ns, and equipotential lines for electric discharges.

CONCLUSIONS

In this paper, we are modeling the breakdown phenomena in the parallel-plate gap filled with helium at atmospheric pressure. From numerical calculations it can be seen that the streamer starts to form, when the concentration of electrons and ions is higher than 10^{10} cm^{-3}. The place where the streamer forms depends on the rate of voltage increasing and on the sufficient electrical field between dielectrics.

We assumed three points at surface of the insulator where a initial electron density is two order higher than the density in the space of electric gap. Hence a number of plasma channel between electrodes depends on heterogeneous density of electrons on a insulator surface.

The results present different discharge phases, a homogenous and a space-charge dominated avalanche phase, a phase with field enhancement due to positive ions causing cathode and anode streamer formation.

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KOMPUTEROWE MODELOWANIE MIKROWYŁADOWAŃ W UKŁADZIE ELEKTROD POKRYTYCH DIELEKTRYKIEM

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Streszczenie. W niniejszej pracy wykorzystujemy dwuwymiarowy, samouzgodniony model płynowy do symulacji komputerowej zjawiska wyładowania elektrycznego w gazie pod ciśnieniem atmosferycznym w wąskiej szczelinie pomiędzy dwiema płaskimi elektrodami pokrytymi dielektrykiem. Wyniki przeprowadzonych obliczeń pokazują różne fazy rozwoju takich wyładowań w konsekwencji prowadzące do powstawania "streamera".

Słowa kluczowe: modelowanie komputerowe, mikrowyładowania, streamer.