Dynamics contraction of DC glow discharge in argon

To cite this article: A I Saifutdinov et al 2016 J. Phys.: Conf. Ser. 669 012045

View the article online for updates and enhancements.
Dynamics contraction of DC glow discharge in argon

A I Saifutdinov¹,², A A Saifutdinova¹, N F Kashapov¹ and S A Fadeev¹
¹Kazan Federal University, Institute of Physics, Kazan 420008, Kazan, Russia
²St. Petersburg State University, Faculty of Physics, 198504, St. Petersburg, Russia

E-mail: as.uav@bk.ru

Abstract. The article presents the results of modeling the dynamics contraction of DC glow discharge. The proposed model can be an important tool in the calculation of devices based on glow discharge plasma at high (up to atmospheric) pressure. Furthermore, the model can be used.

1. Introduction

As is well known, it is difficult to obtain a stable glow discharge at relatively high pressures and currents. Contraction of the positive column is formed under these conditions. This phenomenon in atomic and molecular gases and their mixtures, which are working mixture gas lasers, occurs in plane channels and cylindrical discharge tubes. On the one hand, constriction of the discharge phenomenon is negative, which leads to failure of lasing, which limits energy contribution to the active medium. On the other hand, the detachment of the plasma from the wall of discharge tube is helpful in solving problems of spectral analysis of gas mixtures. In addition, based on the contracted discharge plasma developed inertial sensors that allow for the displacement of the plasma column to produce an electrical signal proportional to the acceleration.

However, in those and other cases to analyze and predict the behavior of devices and systems in which there is a DC glow discharge constriction is requires the involvement of both experimental and theoretical methods.

2. Model description

As is well known [1, 2, etc.], The main reasons for the contraction of the positive column are: a) A non-homogeneous heating of the gas with a maximum temperature on the tube axis, which leads (in view of constant pressure) to displace the neutral particles to the periphery. This leads to an increase in the reduced electric field \( E/N \) in the axial part of the column. Since the ionization rate very strongly (exponentially) depends on the reduced field, it is already a slight increase in this parameter in the axis leads to a strong contraction of the ionization zone; b) The nonlinear dependence of the ionization rate on the electron density (the degree of ionization \( n_e/N \)). Maxwellization of electron distribution function (EDF) due to collisions between the electrons leads to an exponential growth in the rate of ionization with increasing \( n_e/N \). Therefore, a decrease in the degree of ionization in the periphery also leads to delays in the area of charged particles; c) The basic process of electron loss occurs due to volume recombination.

It is worth noting that in the plasma glow discharge elastic scattering of electrons is isotropic. It plays main role in the formation of the EDF. The source of the anisotropy is the external field. Therefore \( f_{orj} \) decomposition [1] holds for EDF. Since in a contracted positive column EDF...
is Maxwellian due to electron-electron collisions, then a chain of kinetic equations for $f_e-f_i$ considering Maxwell's EDF is easy to obtain a fluid approximation [2], which with sufficient accuracy allows to describe the constricted DC glow discharge from the cathode to the anode.

In this paper was considered the glow discharge at high pressure in an inert gas – argon at conditions when the state of discharge is constricted. Numerical experiments were based on the drift-diffusion model, which was formulated in [3-8].

The model is based on balance equations for the densities of charged (electrons, ions) and the excited particles, the electron energy density, heat equation, which takes into account the heating of the heavy particles in the plasma and the Poisson equation for the potential $\varphi$. The stationary state was determined by solving the time-dependent equations. Detailed description of the model and method of the numerical solutions have been considered earlier in [9]. The calculations were made for argon using a kit comprising 23 plasma-chemical reactions [9], and taking into account the two effective excited atomic level $^*\text{Ar}$, and one excimer level $^*\text{H}_{\text{Ar}}$, two kinds of ions $^+\text{Ar}$, $^+\text{H}_{\text{Ar}}$.

3. Numerical experiments and results

Numerical experiments were carried out for the traditional cylindrical configuration of the discharge tube radius $R=1$ cm and an inter-electrode distance $L=4$ cm. The gas pressure was 50 Torr. The voltage at the source was set to $\varepsilon_s = 2 \, \text{kV}$, ballast varied from 10 to 100 kOhms.

Was obtained spatio-temporal pattern of distribution of plasma parameters of constricted glow discharge in argon from the cathode to the anode when $\Omega = 20 \, \text{kOhm}$. Thus in Fig. 1-3 shows the main parameters of the constricted glow discharge - the electron density, the temperature of the heavy particles and the plasma potential distribution at the times $t = 1.4 \, \text{mks}$, $t = 1.8\, \text{mks}$, $t = 3.0 \, \text{mks}$, $t = 5.0 \, \text{mks}$ and $t = 100 \, \text{mks}$.

![Figure 1. The spatial distribution of the electron density in DC glow discharge at the moments: a) t=1.4 mks, b) t=1.8 mks, c) t=3.0 mks, d) t=5.0 mks, e) t=100 mks](image-url)

Spatio-temporal pattern formation of the structure of the contracted glow discharge similar to the diffuse form and extends the 3-5 mks:

1) loss of electrons to an anode, in this period significantly increased current density;
2) the process of ionization in the volume of the gas-discharge gap is characterized by the fall of the current density;
3) ionization in the discharge gap, accumulation of ion density near the cathode and the transition to a self-sustaining form of discharge.

The difference lies in the fact that during all the time of formation of the discharge plasma region contracted to a thin cord. The "head" string is distributed at a rate of about $10^6 \text{sm/s}$. Thus it is seen
that heating gas which is observed in the vicinity of the cathode in the first 1 mks, unlike diffuse form discharge begins to spread along the axis of the discharge chamber. A warm front at the same time moving at speed $7 \cdot 10^6$ sm/s. After the "head" cord reaches the counter electrode, there is a sharp drop in the voltage between the electrodes and the substantial increase of the current.

![Figure 2. Spatial distribution of heavy particles temperature in DC glow discharge at the moments вреєения: a) t=1.4 mks, b) t=1.8 mks, c) t=3.0 mks, d) t=5.0 mks, e) t=100 mks](image)

![Figure 3. Spatial distribution of electric potential in DC glow discharge at the moments a) t=1.4 mks, b) t=1.8 mks, c) t=3.0 mks, d) t=5.0 mks, e) t=100 mks](image)

4. Conclusions

Thus, the article presents the results of modeling the dynamics contraction of DC glow discharge. The proposed model can be an important tool in the calculation of devices based on glow discharge plasma at high (up to atmospheric) pressure. Furthermore, the model can be used to test different methods for control DC glow discharge the parameters [9, 11, 12], including to improve their stability.

Acknowledgments

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. The reported study was funded by RFBR, according to the research project No. 16-38-60187 mol_a_dk.

References