The possibilities of control of the characteristics of a glow discharge by using the organization of supersonic gas flow

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Abstract. The possibilities of glow discharges in a supersonic flow which organized in a limited region of discharge are presented.

1. Introduction

The control of the glow discharge characteristics can allow to remove restrictions on its using in the plasma technology under certain conditions. Some results of the novel methods to control parameters of the glow discharge are presented in [1-4]. In [1] a method of enhancing of the glow discharge stability is proposed for a chamber with cathode sections coated by a discontinuous dielectric coating. In this case the average density of electric current in the cathode region decreases and the conditions for the occurrence of instabilities decreasing. The control possibilities of the glow discharge parameters with using magnetic field are described in [2,3]. The method of synthesis of nanomaterials based on ideas [2,3] is presented in [4].

It is known that the glow discharge has self-organized layered structure of near-electrode zones. The zone boundaries correlate with the increasing of electron energy in electrical field. When the gas pressure is changed the zone boundaries are set according to laws of similarity. For example, the law of similarity \( p d = \text{const} \), where \( p \) - \( p \) - pressure and the \( d \) - thickness of the cathode layer, determines the thickness of the cathode layer. But specially organized supersonic flow can break regularities of self-organization of the near-cathode zones and cathode processes in the glow discharge.

Indeed [5,6], although the supersonic gas flow was organized over all interelectrode space, but the concentration of neutral particles could be different in its different regions. This was demonstrated in articles [7-10] where supersonic flow organized in a limited region of the interelectrode space. Because the particle concentration determines the mean free path, the thicknesses of the near-electrode zones will change in the same way.

The next two limiting cases may provide effective control over the distribution of internal parameters of the glow discharge.

The first case is the case of extremely low pressures. In this case the supersonic flow organization can provide necessary conditions for ignition and maintaining the normal glow discharge near the anode. It is worth noting that at excessively low pressures self-sustaining discharge condition is not performed without the organization of supersonic flow.
The second case is the case of medium pressures. In this case, supersonic flow may concentrate discharge in a region where the flow crosses discharge.

2. Experiments

Experiment was conducted in a vacuum chamber where supersonic gas flow was organized perpendicular to the electric field. The flow occupied approximately 10% of the interelectrode space. The air was used as a working gas. Supersonic gas flow was created in the Laval nozzle with a critical section an area of 0.25 mm$^2$. From the chamber, the gas was pumped out through the confuser, which was located opposite the Laval nozzle. The pump power provided the stationarity of the gas dynamic characteristics in the vacuum chamber. One of the electrodes had the disk form and the second was made in the form of a cylinder. Different electrode polarity variants were investigated.

2.1. Pushing the discharge out of the flow area

Figures 1 and 2 show the photos of the glow discharge at middle pressure.

Figure 1 shows the glow discharge in a transverse supersonic airflow. The pressure in the chamber was generated by air at a pressure 18 torr. The distance between the electrodes was 5 cm. The flow velocity was estimated as 506 m/s ($M=1.5$). We used a mean-square velocity formula for air molecules at 298 K. The photograph shows the flow in the positive column. At the intersection of the flow and discharge, visible light is not radiated, it seems as if the supersonic flow cuts the positive column.

![Figure 1](image)

**Figure 1.** The photo of glow of the glow discharge plasma at the pressure $p = 18$ Torr in supersonic flow. Interelectrode space is 5 cm.

A similar effect is shown in Figure 2 (b). Just as in the figure 1, visible light is not radiated in the supersonic flow region.

Thus, it becomes possible to create a zone, where the mean free path of electrons differs from the mean free path of electrons in positive column without supersonic flow. In this zone, electrons do not gain energy necessary for excitation of atoms.
Figure 2. The photo of glow of the glow discharge plasma at the pressure $p = 20$ Torr in stationary gas (a) and in supersonic flow (b). Interelectrode space is 5 cm.

2.2. The discharge is concentrated in the flow region

Figures 3 (a) and 4 (a) show the photos of glow discharge at pressure of 2.3 Torr. The entire interelectrode space consists of cathode regions without the positive column. Figures 3 (b) and 4 (b) show photographs of glow discharge in transverse supersonic airflow. We see a brightly luminous volume of plasma, where the flow acts on the discharge. On either side of the luminous volume of plasma visible light is not radiated. In this way, with the help of supersonic flow, the region can be created, where active excitation of neutral particles occurs.

Figure 3. The photo of the glow discharge plasma at the pressure $p = 2.3$ Torr in stationary gas (a) and in supersonic flow (b). Interelectrode space is 5 cm.
3. Theory

Figure 5 shows the results of a numerical modeling of the glow discharge in the supersonic gas flow. One-dimensional hybrid glow discharge model was based on the balance equations for the concentrations of electrons, as well as the positive and negative ions, on the equation of the electron thermal balance where we account for not only the volume processes but also the thermal conductive spatial transfer, and on the Poisson equation [10]. Simulation of supersonic flow was carried out by tenfold increasing of concentration of neutral atoms over an interval of 2 to 3 cm.

Figures 5 (a) and 5 (b) show distribution of electron concentration of electrons, positive and negative ions. Figure 5 (a) shows cathode discharge zones, the cathode sheath (CS), the negative glow (NG) zone, and the Faraday dark space (FDS). Then the anode sheath (AS) follows, whereas the positive column (PC) is absent. After increasing the concentration of neutral atoms, the structure of discharge changes. Figure 5 (b) shows the reduction of cathode regions to a sharp border, which coincides with the flow boundary. In addition, the PC occurs; the first half is located within the section with the supersonic flow and the second one comes after this section. We obtained similar results in the laboratory experiments [7].

Figure 5. Parameter distribution of the glow discharge plasma at the pressure $p = 0.15$ Torr with the interelectrode spacing 4 cm without (a) and with (b) supersonic air flow: concentrations of electrons - 1, positive - 2 and negative - 3 ions [10].
4. Conclusions
In the discharge gap the non-uniform distribution of neutral particles directly affects the distribution of electrical discharge parameters and the distribution of charged particles in the interelectrode space. It is shown that with the help of supersonic gas flow we can control the localization of cathode zones. Supersonic flow in a limited region of the interelectrode space solves the problem of controlling parameters in a discharge chamber and opens up new possibilities for using of a glow discharge.

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Acknowledgments
The work was fulfilled with the assistance of a grant of the Ministry of Education and Science of the Russian Federation №3.6564.2017/8.9.

The authors are grateful to Senior Lecturer of the Department for Foreign Languages of the Kazan National Research Technical University named after A. N. Tupolev – KAI Lidiya Urmanova for valuable comments of the translation of this paper.