Internal characteristics of distribution of glow discharge at supersonic speed gas flow in the positive column area

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Abstract. A discharge device providing the ability to create an area in the interelectrode space with a controlled concentration of neutral particles due to the supersonic flow arrangement has been developed and implemented. The possibility to control the internal discharge parameters distribution by supersonic gas flow arrangement in a limited area of the glow discharge is shown experimentally.

1. Introduction
A number of studies [1-9] of the glow discharge in a supersonic gas flow in a limited area of the interelectrode gap were carried out. In these studies, the possibility of controlling the internal discharge characteristics distribution is shown. The present study continues this work and shows the results of experiments on the glow discharge in a supersonic gas flow arranged in a limited area of interelectrode space study. Different situations are possible. In the gas flow, the concentration of gas particles may be higher or lower than the concentration of particles in the other parts of the discharge area, depending on the working gas flow rate, vacuum pumps power, methods of arrangement the supersonic flow. An increase or decrease in the concentration of neutral gas particles leads to a change in the reduced electric field strength E/n and, consequently, to a change in the conditions for the existence of a discharge. The conditions of ionization and excitation of gas particles change accordingly. This paper studies the glow discharge under conditions when supersonic gas flow reduces the concentration of neutral particles in the supersonic flow area compared to other areas of the interelectrode space.

2. Experiment
Figure 1 shows the scheme of the experimental installation. It provides opportunity to study the glow discharge limited by the walls of the chamber (4). The distance between the electrodes (2, 3) of the discharge chamber is 50 mm. The system "nozzle (5) - diffuser (1)" is located at a distance of 15 mm from the anode. The diameters of the copper electrodes are 20 mm. The chamber is equipped with electrodes water cooling. This circumstance made it possible to obtain the volt-ampere characteristics of the glow discharge with a cold cathode. The Laval nozzle and shaped supersonic diffuser were used for arrangement of supersonic flow in the positive column. The Laval nozzle critical throat diameter is 0.66 mm, exit diameter - 2 mm. The walls of the vacuum chamber (4) are made of molybdenum glass.
Figure 1. Scheme of the experimental installation for studying the glow discharge limited by walls

Figure 2 shows the current-voltage characteristics for glow discharge with supersonic air flow in a limited area of positive column for three different air flows going through the nozzle and the corresponding pressure values in the chamber. The current-voltage characteristics for glow discharge with supersonic air flow in the region of a positive column turned out to be decreasing. With an increase in the discharge current, the characteristic gradually changes to saturation mode. It should be noted that the discharge voltage increases with increasing of gas flow rate in the nozzle and is approximately twice the glow discharge voltage in the quiescent gas at the same pressure values.

Figure 2. Volt-ampere characteristics of glow discharge with supersonic flow in the positive column at pressure values: 15, 16.5 and 19 Torr

Figure 3 (a) shows the picture of glow discharge glowing in quiescent gas when air access to the nozzle from atmosphere is blocked (5). Pressure inside the chamber is $p_0$=7 Torr, discharge current is

\[ \begin{align*}
  p_0 &= 15 \text{ Torr}, \ G = 12.7 \text{ mg/s} \\
  p_0 &= 16.5 \text{ Torr}, \ G = 16 \text{ mg/s} \\
  p_0 &= 19 \text{ Torr}, \ G = 22.2 \text{ mg/s}
\end{align*} \]
$I=25\text{mA}$. In the picture of the glow between the cathode (2) and the anode (3), we can see a positive column as well as cathode and anode glow.

The reduced electric field strength $E_0/n_0$ in the area of the positive column at a distance of 15 mm from the anode is equal to $E_0/n_0 = 30 \text{ Td}$ at the discharge voltage $U_0=700 \text{ V}$ and the concentration of neutral particles $n_0=2.2\cdot10^{23} \text{ m}^{-3}$.

The picture of the glow discharge glowing changes significantly after the supply of supersonic air flow with a flow rate of 9.4 mg/s to the glow discharge area at a distance of 15 mm from the anode, which is shown on the Figure 3 (b). The figure shows that between the cathode (2) and the anode (3) in the visible range there is a non-luminous plasma area. This section is located strictly in the space between the Laval nozzle (5) and the diffuser (1).

We estimated the neutral particles concentration in the supersonic flow $n$ in the flow area for the glow discharge shown on the Fig. 3 (b) at a pressure of $p=7 \text{ Torr}$. Design speed of the flow particles is $v=654.3 \text{ m/s}$, the concentration of neutral particles in the flow $n$ is $n=1\cdot10^{23} \text{ m}^{-3}$. Thus, the concentration of neutral particles in the supersonic flow area drops by a factor of 2.2. Considering that the field strength $E$ is not significantly different from those in the previous case, it is possible to estimate the reduced electric field strength. In this case, reduced electric field strength $E/n$ is approximately 67 Td. The received $E/n$ value exceeds approximately 2 times the value of the reduced electric field strength received for experiments without supersonic flow. Apparently, in the supersonic flow area on Figure 3(b), there is ionization of neutral particles. This explains the absence of glow in the visible range of the supersonic flow area.

![Figure 3](image)

**Figure 3.** Glow discharge glowing at a pressure of 7 Torr: a) in the quiescent air; b) in the supersonic air flow, arranged near the anode

Figure 4 shows volt-ampere characteristics of the glow discharge in quiescent gas and in the supersonic air flow at a pressure of 7 Torr. These characteristics correspond to the case of normal glow discharge.
Figure 4. Volt-ampere characteristics of the glow discharge in the quiescent air and in the supersonic air flow near the anode at a pressure of 7 Torr

3. Conclusions
Thus, regardless of the type of discharge (whether it is limited by the walls or burning in the diffuse mode), it is possible to provide a lower concentration of neutral particles in the supersonic flow area by means of a supersonic gas flow and, consequently, receive a higher value of the reduced electric field strength $E/n$ in comparison with neighboring areas. In the experiments of reducing the neutral particles concentration in the positive column area, the effective area demonstrated the absence of radiation in the visible range. Apparently, ionization of neutral particles occurs at the intersection of a supersonic flow with a positive column.

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