Glow Discharge Characteristics in Transverse Supersonic Air Flow

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Abstract. A low pressure glow discharge in a transverse supersonic gas flow of air at pressures of the order 1 torr has been experimentally studied for the case where the flow only partially fills the inter electrode gap. It is shown that the space region with supersonic gas flow has a higher concentration of gas particles and, therefore, works as a charged particle generator. The near electrode regions of glow discharge are concentrated specifically in this region. This structure of glow discharge is promising for plasma deposition of coatings under ultralow pressures.

1. Introduction
One of the necessary conditions for the existence of glow discharge is the presence of all near electrode regions. The length of these regions increases with a decrease in pressure. This is due to the fact that the length of each zone is mainly determined by the number of ionizing collisions of electrons with neutral particles. This result leads to the fact that in a high vacuum for self-organization it lacks the interelectrode space, and the discharge fails to ignite.

In devices of the plasma coating, this problem is solved by applying a magnetic field, which significantly increases the possibility of collisions between electrons and neutral particles due to the combined action of electric and magnetic fields on moving charges and provides the necessary conditions for the existence of the discharge.

However, there is another approach, which implies formation of different concentrations of neutral atoms in different regions of the interelectrode gap. The concentration of gas particles near the cathode should be such in order to mean free path was greater than the distance between the electrodes and ejected from the cathode due to ion bombardment, were not scattered by neutral gas particles. Whereas the concentration near the anode should be sufficient for the electron to undergo several tens of collisions. These requirements can be satisfied by providing supersonic gas circulation in the direction perpendicular to the electric field.

The glow discharge in a supersonic gas flow in supersonic nozzles with a central body was studied in [1–5], where highlighted advantages of supersonic gas flow through the discharge region. In these studies, the discharge was ignited between the nozzle-anode and cathode-central body. In such devices, the glow discharge was self-organization thus in order to for the discharge was needed minimum voltage. In these studies, was noted the stability conditions even at high power discharge,
because the thermal energy in the discharge effectively took away gas flow. Also the influence of supersonic flow on the discharge was considered in [5].

In paper [6] investigated the glow discharge at low pressures with different density of gas in the discharge gap. Unequal particle density in the discharge gap created by the system diffuser - confusor which provides an increased concentration of the gas particles in the area, the boundaries of which are the boundaries of the supersonic flow.

2. Experiment

Block diagram of the experimental setup for investigating glow discharge in a transverse supersonic gas flow is shown in Fig. 1. The setup is a vacuum chamber with two platelike copper electrodes placed opposite to each other at a distance of 5 cm. Pressure in the chamber was 1 Torr. Supersonic pumping system carried through a Laval nozzle - confusor. Confusor connected to a vacuum pump, and through it occurred pumping gas from the chamber.

Due to low pressure in the chamber all the entire interelectrode gap consists of near cathode regions that are necessary for maintaining discharge, also observed negative glow, the cathode and anode spot (Fig. 2.1, 2.2). Feed atmospheric air through a Laval nozzle in the region between the anode and cathode leads to the appearance the positive column. Discharge distinctly shows the boundaries of the gas flow (ris.3.1-3.4).

Fig. 1. Schematic of the experimental setup: (1) power supply, (2) ballast resistance, (3) vacuum pump, (4) confusor, (5) amperemeter, (6) anode, (7) cathode, (8) voltmeter, (9) vacuum chamber, (10) Laval nozzle, and (11) gas inlet valve.

Fig. 2.1. Glow discharge at copper electrodes in Fig. 2.2. Photo of the cathode spot without
air under low pressure without supersonic flow. Supersonic flow. Cathode left, anode right. Cathode left, anode right.

The boundary of the supersonic flow coincides with the boundary of the positive column and the Faraday dark space. Due to reduce of the mean free path in a supersonic gas flow is declining cathode region. At that the gas pressure in the chamber is not changed, since the gas flow hits the confusor and successfully removed from the discharge area. Positive column has sharp boundaries. Carried out a series of experiments to study the effect of a supersonic gas flow on the location of the positive column. In these experiments, a supersonic flow was organized in different parts of the electrode gap. In all these experiments, the observed binding of the positive column border to the border region of supersonic flow.

Also, when certain expenses of air supplied to the discharge region, there was a lack of any glow only in the discharge gap, the boundaries of which coincide with the boundaries of the flow (Figure 3.2), as if the flow of "cuts" discharge. This can be explained by the fact that in the area of influence of flow on the discharge sharply increases the concentration of neutral atoms. Electrons, which committed acts of ionization has is not enough energy to excite the atoms of the air in the segment flow restriction of in this area, and there is no glow, which observed after border flow, since electrons can gain energy.

Along with the reduction of the cathode region and the emergence of the positive column with a clear boundary, and the effect of "cutting" the discharge was discovered phenomenon brightly glowing border outbound flow from the nozzle (Figure 3.3), and at a certain flow rate observed two boundaries, between which there is no illumination (Fig. 3.4).

Fig. 3.1. Clear boundary of the positive column in the presence supersonic flow. 1 – cathode 2 – anode 3 – confusor.

Fig. 3.2. "Cutting" discharge supersonic flow. Cathode left, anode right.

Fig. 3.3. The emergence of a bright border supersonic flow after the supersonic flow. Cathode left, anode right.

Fig. 3.4. The emergence of two glowing borders supersonic flow. Cathode left, anode right.

Moving away from the cathode, the electrons are gradually gaining sufficient energy to excite atoms, approaching the first boundary of the stream, where the concentration of neutral particles is
already significantly higher. Therefore we see the first glowing flow boundary. Further, electrons pass into area where the reduced mean free path and they will not have enough energy to excite the atoms of air.

![Image of I-V characteristic of the glow discharge (1) in supersonic flow and (2) in its absence.]

Figure 4 (curve 1) shows the I–V characteristic of the discharge with the supersonic flow switched on. It can be seen that this characteristic began rising and the discharge voltage is higher than that in the absence of gas circulation. The increase in the discharge voltage can easily be explained by the formation of an extended positive column. The voltage drop at the positive column additionally increases the discharge voltage. However, the increase in the discharge voltage depends on the position of the supersonic flow in the interelectrode gap. For example, when the supersonic flow is formed near the cathode, the discharge voltage increases even more. The fact that the I–V characteristic begins rising after the formation of the supersonic flow can be explained by the influence of the flow on the characteristics of both the positive column and the near electrode regions.

4. Conclusions
The formation of a supersonic gas flow in the limited region of the interelectrode gap makes it possible to control the near electrode processes in a glow discharge. The results obtained determine a new tendency in the technology of plasma deposition of coatings. Transverse supersonic gas circulation allows one to use plasma deposition systems without constant magnets and to increase significantly the cathode sputtering efficiency.

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