Application of low-pressure glow discharge in transverse supersonic gas flow

D I Israphilov, I H Israphilov
Kazan Federal University, Mira prospect, Naberezhnye Chelny, 423823, Russia
diisrafiloc@kpfu.ru

Abstract. Article presents application of glow discharge at low pressures in transverse supersonic gas flow limited in part of discharge region. Mathematical model of supersonic flow in a vacuum chamber described. Results of experiments on realization of glow discharge at low pressures due to the organization of a transverse supersonic gas flow are given.

1. Introduction
Ways to use glow discharge for surface treatment of parts are constantly expanding. Ion-plasma spraying of material or surface modification is increasingly used in industry, electronics, and many other fields. One of the modern directions of implementation is additive technologies.

In the ion-plasma process, it is a prerequisite that the particles reach the surface to be processed without hindrance. To achieve this condition, the free path length $\lambda$ of the particle must be several times greater than the distance $L$ from the beginning of the movement to the surface to be processed.

The main requirement for the implementation of the glow discharge is the presence of all electrode zones. The length of each discharge zone is determined by the number of collisions of the electron with neutral particles. As the pressure $P$ decreases, the length of the near-cathode zones increases, which can lead to the fact that there is no space left in the interelectrode gap for all the near-electrode zones. Thus, at very low pressures, the discharge cannot exist. The critical pressure at which the discharge is still possible is 4.2 Pa, provided that the discharge is cold, the interelectrode distance is 10 cm and the number of collisions is 10, which means [1]. Thus, the existence of a glow discharge at pressures below 4 Pa.

Thus, it is difficult to solve the problem: on the one hand, for the existence of a glow discharge, a pressure above 4.2 Pa is necessary, and for the use of a glow discharge in coating processes, the lowest pressure below 0.1 Pa is necessary.

In works [2-5], an original solution to this problem is proposed. In particular, they suggest creating zones with different concentrations of neutral particles in the interelectrode gap. For example, in the near-cathode zone, create a pressure of 0.01 Pa, which will allow particles to move freely, and in the near-cathode zone, provide a pressure of about 10 Pa of the working gas, for example, argon or air. Electrons trapped in an area with a high concentration of neutral particles can experience dozens of collisions with neutral particles, while the material processing process will take place at the lowest possible pressures. This effect can be achieved when separating zones in the interelectrode gap due to the supersonic gas flow, which will allow to maintain the glow discharge, keeping the pressure in the chamber below 1 Pa.
To create zones with different particle concentrations in the chamber, a device is required (Fig.1), which ensures the organization of a continuous supersonic flow and its pumping out of the vacuum chamber, using a supersonic nozzle and a mixing chamber. In the mixing chamber, the flow is restored and pumped out by a pump. Under certain conditions, this device can work as a jet pump, which will not only save the initial pressure in the chamber, but also lower it.

Fig. 1. Device for organizing a low-pressure glow discharge.

2. Researches
The aim of the research is to create a model of supersonic flow and conduct research for the application of a glow discharge at pressures of 0.01 Pa, to obtain coating of copper.

On the basis of the obtained model [6-7], the geometric dimensions of the elements of the nozzle-mixing chamber system are obtained. The pressure parameters were as follows: at the nozzle inlet, $P_1=1\ \text{atm}$, in the vacuum chamber $P_2=0.01\ \text{Pa}$, in the pumping system to the pump $P_3=8\ \text{Pa}$, argon gas. Simulation results (Fig.2) indicate the possibility of creating and pumping out a continuous flow in a vacuum in the interelectrode gap to obtain zones with different particle concentrations.
After the working gas is supplied to the nozzle, the pressure in the chamber remains unchanged (Fig. 3), since the supersonic flow is continuous [8]. The flow is restored outside the chamber, after passing the mixing chamber.

For simulating a glow discharge, the following form was adopted (Fig. 4). The potential difference between the cathode and the anode is 1250 V. in the interelectrode gap, an area of high particle concentration is organized in the device (Fig. 1) by maintaining a continuous flow.

As a result of the obtained experimental studies, a glow discharge was performed at a pressure in the vacuum chamber \( P_2 = 1 \) Pa [3, 9] (Fig. 6). a coating of copper was obtained (Fig. 7)
3. Conclusion

Based on the simulation and experimental studies, the parameters of the supersonic flow in the vacuum chamber and the characteristics of the glow discharge with transverse supersonic pumping of the working gas flow are obtained.

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