Features of Glow Discharge burning between a hollow cathode and a mesh anode

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Abstract. The article is devoted to an experimental study of the features of the combustion of a glow discharge between a hollow copper cathode and a mesh anode in a longitudinal air flow. The cylindrical channel of the discharge chamber was formed by five glass sections separated by copper plates, which served as probes for measuring the plasma potential. Air flowed through the hollow cathode into a cylindrical channel. The anode was a metal grid of a copper plate 1.5 mm thick with holes uniformly located on it with a diameter of 1 mm. The distance between the hollow cathode and the mesh anode was 6.5 cm. Air pressure P, its velocity V, discharge current I and its voltage U varied respectively in the ranges: P = (6.4 - 19) kPa, V = (0 - 10) m / s, I = (5-100) mA, U = (1.0 – 2.0) kV. The current-voltage characteristic had a negative differential resistance. By changing the ballast resistance, the forward and reverse branches of the current-voltage characteristic were removed. It was found that in the range of discharge currents I = (40-80) mA, these branches do not coincide, that is, hysteresis phenomena were observed. In the ascending branch of the current-voltage characteristic in the region of the current strength I = 80 mA, the discharge voltage increases sharply from U = 1.2 kV to U = 1.6 kV. In this case, the discharge glow becomes more intense, wider and brighter, and the structure of light and dark zones along the discharge chamber also changes. Characteristic photos of the discharge are given. The formation of luminous and dark gaps inside the positive column of the discharge and their movement towards the anode was detected.

1. Introduction
Glow discharge plasma is widely used in gas-discharge light sources, as the active medium of gas lasers [1-3], in modern technologies for producing various coatings, nanotechnological methods for producing non-traditional materials, and plasma monitors. Therefore, the study and investigation of glow plasma parameters is of scientific and practical interest [4-10]. One of the differences of a glow discharge in comparison with other types of discharges is a significant excess of the electron temperature over the temperature of neutral particles. This allows the use of a glow discharge in various technological processes requiring low gas temperatures (plasma chemistry, cathodes atomization of metals, film deposition, and surface modification) [11-14]. Despite the fact that different types of discharges have their own characteristics, many of the problems under study are similar [15-23]. For the required technological purposes, discharge chambers with various forms of electrodes, schemes of their location and organization of gas flows are used. The importance of the study of such characteristics is due to the fact that they allow us to develop and automate the
technological process of plasma processing of materials. The aim of this work is to study the effect of the geometry of the discharge chamber, the shape of the electrodes and gas parameters on the combustion characteristics of a longitudinal glow discharge.

2. Experiment
The scheme of the experimental setup is shown in Figure 1.

![Diagram of experimental setup](image)

Figure 1. The scheme of the experimental setup: a - gas-dynamic path, b - discharge chamber

Air through the needle leak detector 1 and the flow meter 3 (RDS-10 rheometer) was fed into the discharge chamber 4. The discharge chamber is a quartz tube consisting of separate sections (Fig. 1.b). The discharge ignited in the longitudinal flow between the copper hollow cylindrical cathode 8 and the copper mesh anode 9. The inner and outer diameters of the hollow cylindrical cathode were 10 mm and 16 mm, respectively. Through the inner channel of the cathode, gas entered a cylindrical channel with a diameter of 18 mm, formed by individual quartz sections. Between the sections forming a cylindrical channel, there are five 0.2 mm thick copper plates 10 serving as probes for measuring potential. The mesh anode is a 1.5 mm thick copper plate and overlaps the internal channel of the discharge chamber. The anode plate contains many holes with a diameter of 1 mm, through which the gas flows. The distance between the electrodes was 6.5 cm. The spent medium from the discharge chamber entered the tank and was removed to the atmosphere with a vacuum pump BBH-12. The static pressure in the discharge chamber was measured with U-shaped mercury manometers 2 and 5. The flow rate and pressure value P was controlled by valve 6. The discharge voltage fluctuations were recorded with type CI-48B oscilloscope 7, and the current-voltage characteristic of the discharge was
recorded with a two-coordinate type recorder H-306. The ballast resistance $R = 36 \, \text{k}\Omega$ was included in the discharge circuit. The floating potential was measured with a C-50 electrostatic voltmeter.

3. Results

Figure 2 shows the current-voltage characteristic of a glow discharge in a stationary gas for a pressure of $P = 8.9 \, \text{kPa}$.

![Figure 2. Voltage -current characteristic of a glow discharge in a stationary gas.](image)

Triangles on this curve mark all characteristic points of the current-voltage characteristic. The characteristic itself has a falling form, which is characteristic of this type of discharge. It can be seen that with an increase in the voltage of the power supply, the voltage across the discharge gap decreases, and the current increases to $I = 80 \, \text{mA}$. However, starting from this value, a further increase in the voltage of the power source leads to a sharp increase in the voltage across the discharge gap (straight line 2-3 in Fig. 2) and a decrease in the current strength. At the same time, the power invested in the discharge increases, the discharge acquires a bright white color. Restructuring of the discharge begins with a current strength of $I = 70 \, \text{mA}$. Prior to this, the current values of the glow discharge had all its characteristic regions: luminous films on the cathode and anode, dark space near the cathode. In the range of current strength $I = (70-80) \, \text{mA}$, the voltage across the discharge gap begins to increase slightly (section 1-2 in Fig. 2). Then the voltage rises in the range $U = (1.2 - 1.6) \, \text{kV}$ (section 2-3). Then, with a decrease in current strength, a voltage drop is already observed (plot 3-4-5 in Fig. 2). In this case, the shape of the discharge, the distribution along the length of dark and bright spaces, and the intensity of the glow changed. The dark region near the cathode practically disappears, while a dark region appears near the anode. On the surface of the anode, the glow is noticeably enhanced (Fig. 3).

![Figure 3. Photos of the discharge: on the left $I = 70 \, \text{mA}, U = 1.15 \, \text{kV}$, on the right $I = 80 \, \text{mA}, U = 1.2 \, \text{kV}$](image)

The photographs on the left are the cathode and on the right the anode. The photographs also show the locations of the copper plates serving as probes. It is also noticeable that in the indicated range of variation of the current, in general, the discharge glow decreases. In the area of decreasing current in
the range $I = (80-65)$ mA, the discharge voltage increases sharply in the range $U = (1.2 - 1.6)$ kV and the type of discharge takes on a different form (Fig. 4)

![Figure 4. Photos of the discharge: on the left $I = 65$ mA, $U = 1.6$ kV, on the right $I = 80$ mA, $U = 1.6$ kV](image)

It can be seen that in these modes the plasma column is wider and brighter. An analysis of the experimental data showed that the processes of changing the shape of the discharge are non-stationary in nature and somewhat resemble the movement of striations.

Some results on the distribution of potential are shown in Figure 5

![Figure 5. Potential distribution along the length of the discharge chamber: $G = 0$, $P = 4$, $6$ kPa; $1$ - $I = 50$ mA, $2$ - $I = 30$ mA, $3$ - $I = 20$ mA](image)

In these graphs, the cross section $z = 0$ corresponds to the end of the cathode, whose potential is taken equal to zero. The gas flow rate $G = 0$. The potential value from the cathode to the anode grows approximately linearly, and the electric field strength remains almost constant. The average electric field strength of the discharge decreases with increasing current, which is consistent with the incident current-voltage characteristic.
4. Conclusions
In this paper, we studied the combustion features of a longitudinal glow discharge between a hollow cathode and a mesh anode, measured current-voltage characteristics, and also the potential distribution along the length of the discharge chamber. Hysteretic sections of the current-voltage characteristics of the discharge were detected. In these areas, changes in the shape and glow of the discharge occurred, as shown in the photographs. Changes in the luminous and dark regions of the discharge are unsteady and wave-like. A possible mechanism for the appearance and disappearance of striations in this work is associated with the shape of the anode, which to some extent creates a barrier to the gas flow and is a source of disturbance. Another reason may be the plasma-chemical processes occurring inside the discharge. The measured potential distributions are consistent with the known data in an unperturbed glow discharge.

References
[1] Raizer Y P 1992 Gas Discharge Physics (Moscow: “Science”) p 536
[2] Kiselev A S et al. 2017 Journal of Physics: Conference Series 789 012027
[3] Ramazanov A N et al. 2016 Journal of Physics: Conference Series 729 012004
[4] Yunusov R F 1985 Journal of Engineering Physics and Thermophysics 48 591-592
[5] Yunusov R F 1985 Journal of Engineering Physics and Thermophysics 48 214-219
[6] Yunusov R F 1985 Soviet Aeronautics 28 78-82
[7] Yunusov R F 1988 Journal of Engineering Physics and Thermophysics 54 76 – 80
[8] Dautov G Y and Yunusov R F 1988 Izvestiya Vysshikh Uchebnykh Zavedenii Aviatsionaya Tekhnika 2 21-25
[9] Yunusov R F 1990 Journal of Engineering Physics and Thermophysics 59 990-994
[10] Yunusov R F 1991 Inzhenerno-Fizicheskii Zhurnal 59 990-994
[11] Yunusov F S, Khisamutdinov R M and Yunusov R F 2008 Russian Engineering Research 28 965-973
[12] Yunusov F S and Yunusov R F 2011 Russian Engineering Research 31 15-21
[13] Yunusov F S and Yunusov R F 2011 Russian Engineering Research 31 660-665
[14] Yunusov F S and Yunusov R F 2011 Russian Engineering Research 31 951-959
[15] Tazmeev G K, Timerkaev B A and Tazmeev K K 2019 Journal of Physics: Conference Series 1328 012075
[16] Tazmeev G K, Timerkaev B A and Tazmeev K K 2018 Journal of Physics: Conference Series 1058 012037
[17] Yunusov R F 2017 Journal of Physics: Conference Series 789 012069
[18] Yunusov R F and Garipov M M 2017 Journal of Physics: Conference Series 927 012076
[19] Yunusov R F and Garipov M M 2017 Journal of Physics: Conference Series 927 012077
[20] Yunusov R F, Garipov M M and Yunusova E R 2018 Journal of Physics: Conference Series 1058 012051
[21] Yunusov R F, Garipov M M and Yunusova E R 2018 Journal of Physics: Conference Series 1058 012050
[22] Yunusov R F and Garipov M M 2019 Journal of Physics: Conference Series 1370 012032
[23] G Sh Akhatov et al 2019 Journal of Physics: Conference Series 1328 012004