Investigation of Regularity of Plasma Formation in Large Volume on the Basis of the Hollow Cathode Effect Using High-Frequency Short-Pulsed Voltage

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Abstract – The regularities of the nitrogen and argon plasma formation in a hollow cathode with the volume up to 0.2–0.5 m$^3$ using the short-pulsed (1–10 $\mu$s) high-frequency (100 kHz) voltage to 3 kV are presented in the paper. It is shown that despite the pulsed nature of voltage, the gaseous discharge steadily burns at the pressure of 0.1 Pa and higher, the discharge current value and plasma concentration grow as the voltage pulse duration and voltage amplitude increase, the general discharge current reaches 10 A, providing the density of the ion saturation current on the items placed in plasma up to 0.5 mA/cm$^2$.

1. Introduction

The glow discharge in the hollow cathode represents a unique method of dense plasma formation and is widely used in formation of electron and ion beams [1, 2]. The discharge application in a hollow cathode for the ion treatment of materials in the glow discharge is also known. In most cases of discharge formation they try to decrease the voltage of discharge burning supplying gas directly to the cathode cavity and thus achieving the pressure increase in it. A possibility of formation of a steady glow discharge using repetitively pulsed voltages is shown in paper [3]. When the pulse duration was 0.01–1 $\mu$s, the steady glow discharge was formed at pulse repetition rate of the order $10^3$ s$^{-1}$ in conditions of the magnetic field application with the induction of $B \sim 1–10$ mT.

The present paper is devoted to investigation of regularities of the nitrogen and argon plasma formation in a hollow cathode of large sizes using short-pulsed high-frequency voltage without the external magnetic field application.

2. Experimental setup

The investigations were performed on the unit which schematic is shown in Fig. 1. The cylindrical hollow cathode with the diameter of 60 cm and height of 70 cm was placed inside the vacuum chamber with rectangular cross-section of $70 \times 70$ cm and height of 90 cm. In the upper part of the cathode there was made an orifice with diameter of 15 cm for the gas puffing. The rod tungsten anode with diameter of 1.5 mm was introduced into the hollow cathode through the central part of the lower cavity of the cathode. The source of negative voltage pulses which duration could vary within 1–9 $\mu$s at a fixed pulse repetition rate of $10^2$ s$^{-1}$ was connected to the cathode. Two pulse durations were used in the experiments: 3 and 7 $\mu$s. When the technological regimes of metal plasma deposition from the vacuum-arc discharge were investigated, there were made three orifices in the lateral surface of the hollow cathode with diameter of 20 cm opposite the vacuum-arc evaporators at gaseous plasma formation in the glow discharge with the hollow cathode. In certain experiments the orifices were covered by a tungsten grid with the grid cell size of $\sim 1 \times 1$ mm and the grid transparency of $\sim 0.8$ to diminish the electron drift from the glow discharge.

1.5 mm was introduced into the hollow cathode through the central part of the lower cavity of the cathode. The source of negative voltage pulses which duration could vary within 1–9 $\mu$s at a fixed pulse repetition rate of $10^2$ s$^{-1}$ was connected to the cathode. Two pulse durations were used in the experiments: 3 and 7 $\mu$s. When the technological regimes of metal plasma deposition from the vacuum-arc discharge were investigated, there were made three orifices in the lateral surface of the hollow cathode with diameter of 20 cm opposite the vacuum-arc evaporators at gaseous plasma formation in the glow discharge with the hollow cathode. In certain experiments the orifices were covered by a tungsten grid with the grid cell size of $\sim 1 \times 1$ mm and the grid transparency of $\sim 0.8$ to diminish the electron drift from the glow discharge.

![Fig. 1. Schematic of the setup: 1 – vacuum chamber; 2 – hollow cathode; 3 – rod anode; 4 – high-voltage repetitively pulsed source.](image)

3. Experimental results

The results of investigation of the argon plasma formation in a hollow cathode at different gas pressures and two pulse durations are presented in Fig. 2. When the gas pressure is 0.3 Pa, the discharge ignites at pulse duration of 3 $\mu$s and voltage about 1 kV. When the voltage increases to 3.0 kV, the discharge current gradually grows reaching 6.5 $A$ at $\tau = 3$ $\mu$s and 8 $A$ at $\tau = 7$ $\mu$s. In the pressure range of 0.6–3 Pa, no typical dependences of the current change on the voltage are observed. The discharge ignites at 0.5 kV. Maximum discharge current is about 9 $A$.

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The analog dependences of the discharge current change on the nitrogen pressure at two pulse durations and three voltages are presented in fig. 3. As in the case of argon, the discharge is steadily formed at the pressure above 0.3 Pa. The maximum current in the discharge depends on the voltage to a greater degree and on the pulse duration to a lesser degree. The discharge current remains practically constant within the pressure range of 0.6–3 Pa.

The possibility of the nitrogen and argon plasma formation in a large volume using short-pulsed high-frequency voltage was shown. The dependences of the discharge current on the gas pressure, voltage amplitude, and pulse durations at fixed pulse repetition rate of 100 kHz were obtained.

A possibility of realization of TiN and TiAlN coatings plasma deposition technology with repetitive ion assisting in the mode of high-frequency, short-pulsed plasma-immersion ion implantation [5].

4. Conclusion

A possibility of the nitrogen and argon plasma formation in a large volume using short-pulsed high-frequency voltage was shown. The dependences of the discharge current on the gas pressure, voltage amplitude, and pulse durations at fixed pulse repetition rate of 100 kHz were obtained.

A possibility of realization of TiN and TiAlN coatings plasma deposition technology with repetitive ion assisting in the mode of high-frequency, short-pulsed plasma-immersion ion implantation was shown.

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