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INVESTIGATION OF PULSE GLOW DISCHARGE EXCITATION MODES IN N_2 IN A HOLLOW CYLINDRICAL COMBINED CATHODE

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Abstract. Electric discharge excitation modes and N_2 pressure range for a stable formation and maintaining of pulse glow discharge plasma in a hollow combined cathode have been investigated. It has been found that both of these parameters are influenced by the constructive peculiarities of the cathode. It has been established experimentally that the value of N_2 breakdown voltage for the studied construction of the cathode within the range of 50–250 Pa does not exceed -700 V.

Keywords: hollow cathode, glow discharge, electric pulses, vacuum.

1. Introduction

The application of ion-plasma treatment is characterized by high technological opportunities to change physico-chemical and mechanical properties of constructional materials parts' surfaces because of their complex treatment: obtaining optimal structure, phase composition and the degree of phase doping [1].

Concerning a number of technological problems the use of glow discharge with hollow cathode effect (HCE) for materials heating up in vacuum (including melting) is of interest [2], [3], [4]. It is connected with the fact that a glow discharge with HCE possesses a number of specific peculiarities such as a possibility of significant plasma density increase at a low average power level [5], high temperature in plasma-forming zone because of high power input [6], etc.

The studies of glow discharge plasma-forming with HCE modes are presented in a number of publications. But because of specific construction peculiarities of such plasma discharge systems it is impossible to define in advance the optimal modes of plasma-forming for a certain construction and dimensions of hollow cathode. Besides, the modes of plasma-forming are greatly influenced by such factors as the kind of plasma-forming gas, the frequency and the form of electrical signals exciting the plasma, the form and the location of the anode, the cathode's spatial position, etc.

Therefore, for unconventional hollow cathode constructions the choice of electrical plasma-forming modes and the definition of gas pressure ranges that provide a stable exciting and maintaining of plasma are performed experimentally.

2. Experimental part

The investigation was carried out with the use of a gas discharge system in the form of a hollow cylindrical electrode-cathode (Figure 1) made of stainless steel. The internal diameter of the electrode-cathode body was $D = 60$ mm, the height of the body was $L = 40$ mm.

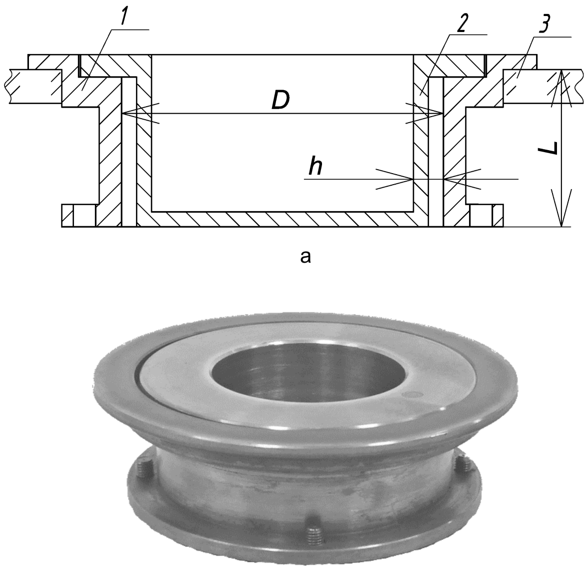

Figure 1. Construction (a) and external view (b) of the hollow cylindrical electrode-cathode

The electrode-cathode consists of a round body 1 which can contain replaceable insertions 2 of various construction. The cathode is held by a quartz plate 3 located on the top end of the vertical quartz cylinder standing on the metal base of the vacuum chamber. Such construction of the electrode-cathode holder provides separation of plasma region (the discharge area is inside the quartz cylinder) from the rest volume of the installation vacuum chamber. A current lead is connected to the body of the electrode-cathode placed inside the quartz cylinder. The voltage is applied to the electrode through it.

The glow discharge in the electrode-cathode is excited in the space h between the internal body surface

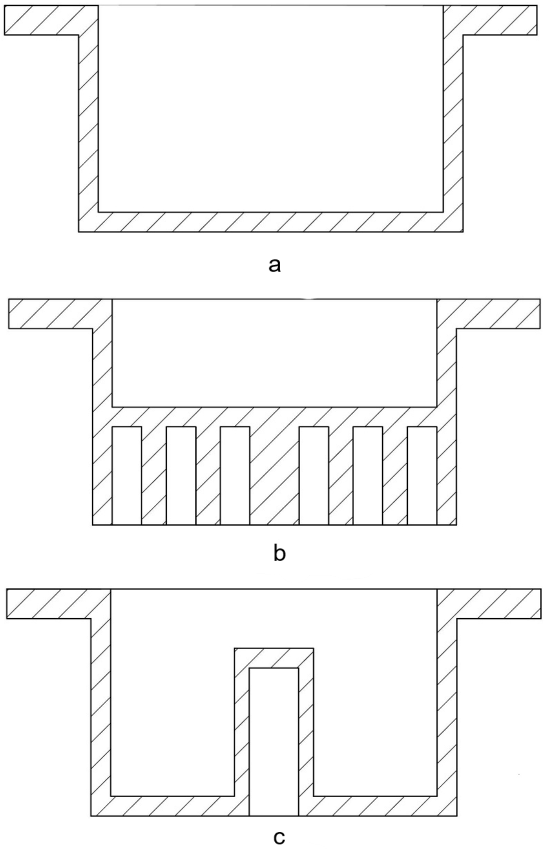

Figure 2. Forms of replaceable insertions of the electrode-cathode; a — solid cylindrical; b — with ring cavities in the bottom part; c — with a hollow protrusion

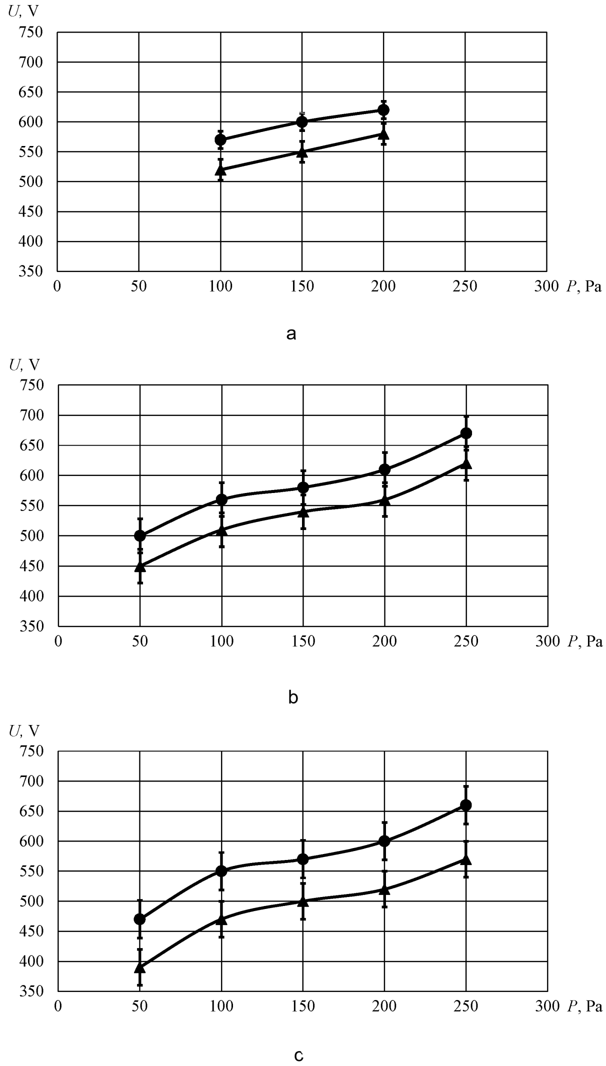

Figure 3. Excitation and extinction voltage of the discharge with HCE in N_2 for solid cylindrical insertions at $h = 2$ mm (a), $h = 3$ mm (b) and $h = 5$ mm (c):
● — *discharge exciting voltage*
▲ — *discharge extinction voltage*

and the external surface of the replaceable insertion. Replaceable insertions of various construction were used during experiments: cylindrical of various diameter (Figure 2a), with ring cavities in the bottom part (Figure 2b), with a hollow protrusion (Figure 2c).

To excite the discharge with HCE the pulse voltage of negative polarity with the rectangular pulse repetition frequency $f = 47$ kHz and pulse ratio $S = 4$ was applied to the cathode.

High purity nitrogen N_2 was used as plasma-forming gas.

The moments of discharge excitation and extinction were defined according to the indications of the plasma optical luminescence sensor connected to an oscillograph.

Before the experiments, the vacuum chamber was pumped out to $P = 1$–2 Pa extreme residual pressure.

During the experiments the ranges of plasma-forming process regulation modes were: the amplitude of generator voltage pulses changed from -300 V to -1000 V; the pressure of N_2 in the vacuum chamber varied within the interval of 30–600 Pa.

3. The results and discussion

The experimental data on the conditions of discharge excitation and extinction for solid cylindrical insertions at various distance h from the insertion's external surface to the electrode-cathode's body internal surface are given in Figure 3.

The presented dependencies show that lower values of discharge with HCE excitation voltage for investigated N_2 pressure ranges are provided at $h = 5$ mm distance between plasma-forming surfaces.

With the decrease of this distance the discharge excitation voltage increases and the N_2 pressure range of discharge with HCE excitation decreases. It may be caused by the increasing probability of plasma particles losses on the cathode surface and the decrease of near to cathode area size in the plasma-forming region.

The value of discharge excitation voltage in the range of plasma-forming gas pressure monotonously increases with the growth of pressure.

N_2 pressure range at which the stable excitation of

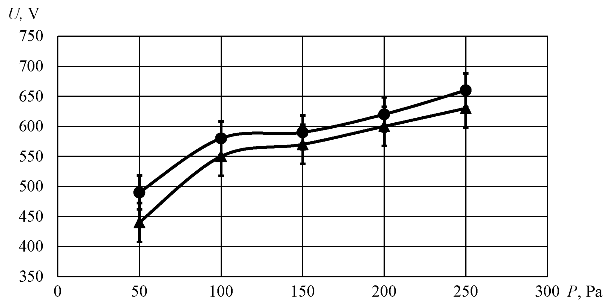

Figure 4. Voltage of discharge with HCE excitation and extinction in N_2 for an insertion with a hollow protrusion:
● — *discharge exciting voltage*
▲ — *discharge extinction voltage*

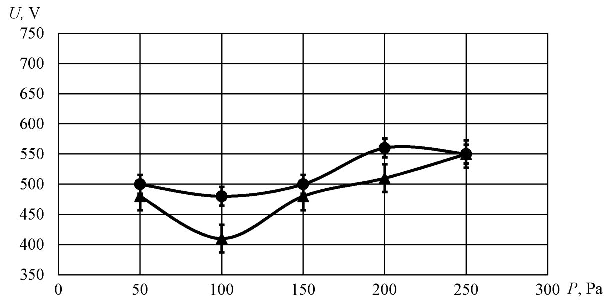

Figure 5. Voltage of discharge with HCE excitation and extinction in N_2 for an insertion with ring cavities in the bottom part:
● — *discharge exciting voltage*
▲ — *discharge extinction voltage*

the discharge with HCE takes place for $h = 5$ mm and $h = 3$ mm was 50–250 Pa. For $h = 2$ mm the range narrowed to 100–200 Pa.

Data analysis of the discharge excitation and extinction values shows that the distance between the walls $h = 5$ mm provides better conditions not only for a breakdown but for maintaining a discharge as well. In this case the discharge disappears at voltage values lower than for $h = 2$ mm and $h = 3$ mm.

The presence of a cylindrical protrusion with the internal diameter $D = 5$ mm in the end part of a replaceable insertion (Figure 2c) has not essentially influenced the modes of exciting the discharge with HCE (Figure 4).

The presence of ring cavities in the bottom part of the insertion (Figure 2b) led to lower values of discharge with HCE excitation voltage in the whole range of plasma-forming pressure (Figure 5).

Note, the discharge with HCE appeared in the cavities as well.

The discharge in cavities at various gas pressure values took place in different ways.

At the pressure about 50 and 250 Pa the discharge appeared only in the outside cavity. The appearance of the discharge in the outside and central cavities was observed at the pressure 100 and 200 Pa. At the pressure about 150 Pa the discharge occurred in all cavities.

Therefore, the performed experiments showed that the exciting of a pulse glow discharge with HCE in the investigated construction of the hollow combined cylindrical cathode in nitrogen at an average vacuum takes place at breakdown voltage values not exceeding -700 V. Consequently, there is no need to use generators with a higher amplitude value of electric pulses.

Note, the exciting voltage of the glow discharge with HCE may be lowered by modifying the electrode-cathode's construction.

4. Conclusions

Electrical modes have been studied and N_2 pressure ranges for a stable formation and maintaining of the pulse glow discharge with HCE plasma in a hollow combined cylindrical cathode have been established.

It has been shown that cathode's constructive peculiarities influence both the electrical modes of discharge formation and the extent of N_2 pressure range in which plasma is formed and maintained.

It has been established experimentally that the values of nitrogen breakdown voltage for the investigated electrode-cathode construction in the pressure range of 50–250 Pa does not exceed -700 V.

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