doi:10.14311/ppt.2018.3.99
Plasma Physics and Technology **5**(3):99–102, 2018

INVESTIGATION OF PECULIARITIES OF THE DISCHARGE EXCITATION WITH HOLLOW CATHODE EFFECT IN N_2 IN A TUBE ELECTRODE

S. Bordusau*, A. Bozhko, S. Madveika, O. Tsikhan, I. Barouski

Belarusian State University of Informatics and Radioelectronics, P.Brovki 6, 220013 Minsk, Belarus

* bordusov@bsuir.by

Abstract. The influence of some constructive discharge system elements on the electric excitation modes and stable maintaining of pulse glow discharge plasma in N_2 in a hollow tube cathode has been investigated. The following discharge system changes have been performed: the position of a hollow electrode-cathode in the dielectric tube-holder; the method of plasma forming gas feeding to the discharge area; the distance between the electrode-cathode and counter-electrode (grounded anode). The investigation has been carried out within 50–700 Pa N_2 pressure range. The obtained results may be used in the design of gas discharge systems with hollow cathode effect.

Keywords: discharge, hollow cathode, vacuum, tube electrode.

1. Introduction

Numerous specific peculiarities of a hollow cathode discharge [1–3], determine its wide application in spectroscopy, microwave devices, various ion devices, for welding and metal melting, etc. [4–7].

Regarding the problems of vacuum-plasma treatment processes intensification the interest concerns the investigation and development of the method of preliminary working gas activation in a separate plasma source [8] which can be based on the use of a hollow-cathode discharge.

A great number of publications deal with the investigation of a plasma forming of glow discharge with a hollow cathode effect mode (HCE) [9–11]. But because of the specific constructive peculiarities of plasma discharge systems of such type, the definition of optimal plasma-forming modes for a definite design and a certain hollow cathode sizes turns to be impossible. Besides, the plasma-forming mode is greatly influenced by such factors as the type of a gas, the frequency and the form of the electric pulses exciting the plasma, the shape and the position of the cathode, the anode's spatial position, etc.

2. Experimental part

The investigation of some gas discharge system design peculiarities influence on the excitation of the discharge with a hollow cathode effect was carried out with the use of a cylindrical tube electrode-cathode held with a quartz tube (Fig. 1).

Hollow cathode 2 was made of corrosion-proof steel in the form of a cylinder with the internal diameter 5 mm and placed at one end of the quartz tube 3. The other end of the tube was led out of the vacuum chamber through a vacuum connection. The quartz tube performs several functions simultaneously: it is an electrode-cathode holder; it provides plasma forming gas feeding through the electrode; it serves as

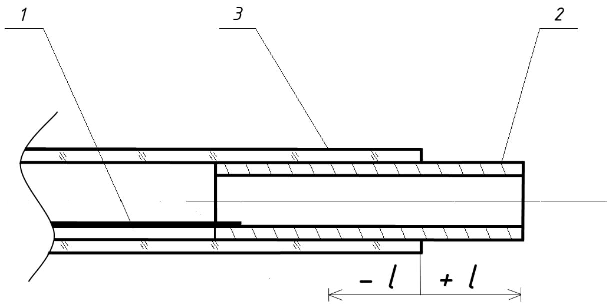

Figure 1. The design of a plasma discharge system:
1 – current feeding wire
2 – tube hollow cathode
3 – quartz tube

a protection screen for the current feeding wire; it is an insulator for a part of the external surface of the electrode.

The electrode-cathode was placed at the distance more than 200 mm from the internal surface of the metallic vacuum chamber.

Several experiments were carried out with the use of a grounded counter-electrode (anode). It was made of corrosion-proof steel in the form of a disk with 100 mm diameter. The disk was placed perpendicularly to the electrode-cathode axis at different distances from it.

To excite the discharge with a hollow cathode effect, a negative polarity pulse voltage with the rectangular pulses of $f = 50$ kHz frequency and pulse off-duty factor $S = 4$ was applied to the cathode.

High purity nitrogen (N_2) was used as a plasma forming gas.

The moments of discharge appearance and extinction were defined according to the indication of an optical plasma glow sensor connected to an oscilloscope.

Before the experiments, the vacuum chamber of

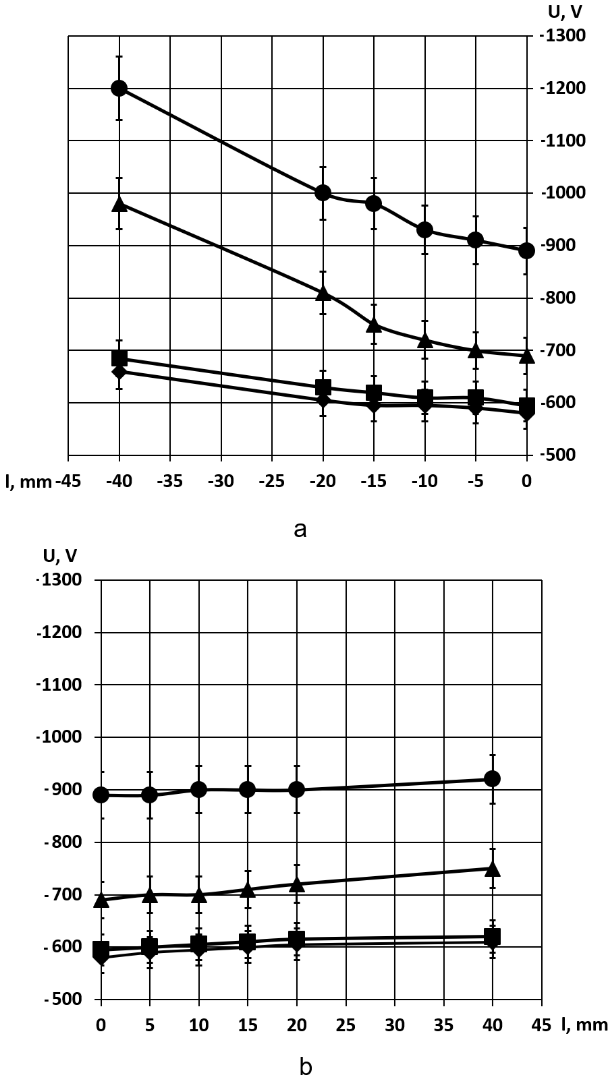

Figure 2. Dependence of discharge excitation voltage values on the cathode's position in the quartz tube at different pressure values (gas – N_2) when immersed into the quartz tube (a), when moved out of the quartz tube (b):
♦ – $P = 50$ *Pa*
■ – $P = 80$ *Pa*
▲ – $P = 225$ *Pa*
• – $P = 330$ *Pa*

the installation was pumped out to the value of the residual pressure not exceeding $P = 1$–2 Pa.

During the experiments, the ranges of plasma forming process modes were: the generator's voltage pulses amplitude was varying from -450 V to -1300 V; the pressure of N_2 in the vacuum chamber of the installation was varying within the range 50–700 Pa.

3. The results and discussion

The experiment's data on the amplitude values of discharge excitation voltage at different cathode positions relative to the quartz tube's end face at various pressure are shown in fig. 2.

The presented dependencies show that extension of the electrode from the quartz dielectric tube within the studied values does not significantly affect the amplitude values of voltage pulses required for the discharge excitation.

With the cathode immersed into the quartz tube we observed a close to the linear dependence of increasing break-down voltage value on the distance from the tube's end face. Note, with the increase of N_2 pressure, the degree of this influence increases. We assume that this effect is connected with the increase of plasma particles interaction with the internal surface of the quartz dielectric tube and respective worsening of plasma forming conditions.

During the experiment, it was established that the position of the hollow tube-type cathode in a quartz tube affects the range of pressure at which the discharge with hollow cathode effect is excited and stably maintained.

The discharge is excited and stably maintained in the range of pressure equal to 50–700 Pa, when the position of the end face of the cathode with respect to the end of the tube was in the interval from $l = +40$ mm to $l = -15$ mm. When the cathode is immersed to more than 15 mm, the range of pressure decreases significantly, particularly its upper bound. The discharge begins to behave unstably or does not excite at pressures exceeding 350 Pa.

It should be noted that the instability, in this case, manifested itself in a quick decay (about 2–3 sec) of discharge and the difficulty in the objective registering its characteristics by oscillogram.

According to the results of the performed experiments, the method of gas feeding into the plasma-formation zone affects the characteristics of exciting and maintaining the discharge with a hollow cathode effect.

Fig. 3 shows the dependence of voltage amplitude values, exciting the discharge with a hollow cathode effect, on the pressure of plasma forming gas at various cathode positions in the quartz tube. The values of Fig. 3a have been obtained for the conditions of gas feeding into the quartz tube not through the discharge system. The data of Fig. 3b have been obtained when the gas passed in the quartz tube through the discharge in the hollow electrode-cathode.

The presented results show that the discharge is excited and glows stably in the range of 50–660 Pa pressure when the plasma forming gas passes through the discharge system, and in a narrower 100–500 Pa range when the gas is fed past the discharge system.

Note, when the gas is fed through the discharge system, somewhat higher values of pulse voltage are required to excite the discharge with a hollow cathode effect. We assume that it can be explained by the following factors: 1. when the plasma forming gas is fed through the electrode of the discharge system, the pressure in its cavity is higher than in the vacuum chamber; 2. the discharge is formed in the stream of the non-activated gas and the area of plasma after-

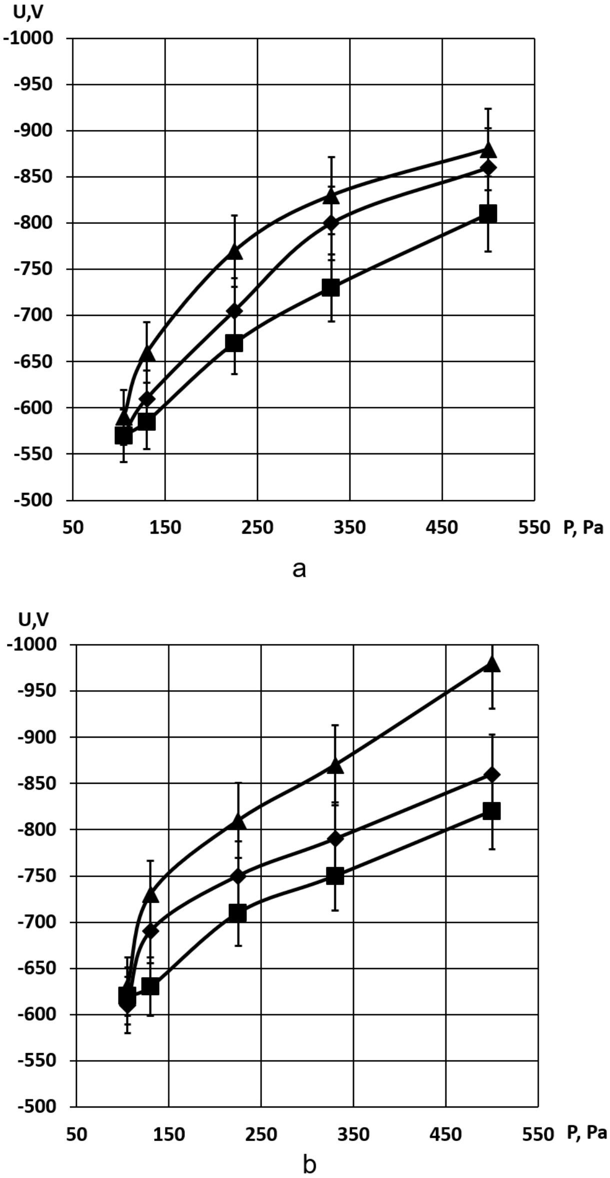

Figure 3. Values of excitation voltage of the discharge with hollow cathode effect in N_2 when the gas was fed past the discharge system (a), through the discharge system (b):
■ – $l = +15$ *mm*
♦ – $l = 0$ *mm*
▲ – $l = -15$ *mm*

glow does not significantly affect the process of plasma excitation.

Concerning possible variants of the design variants and the position of discharge system elements, the influence of the distance between the hollow cathode and the grounded counter-electrode on the value of voltage exciting the discharge with hollow cathode effect was studied.

The obtained data are presented in Fig. 4.

The results of measurements show that the influence of distance between the cathode and the counter-electrode in the range of 110–200 mm on the excitation modes and maintaining of the discharge with a

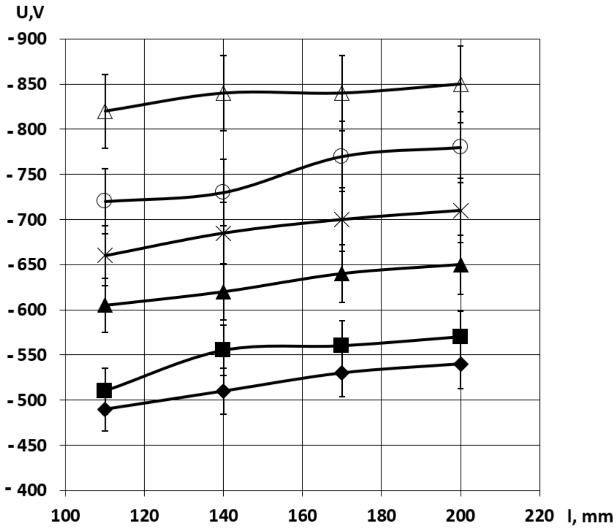

Figure 4. Values of excitation voltage of the discharge with hollow cathode effect when the distance between the cathode and the counter-electrode changes at different pressures:
♦ – $P = 50$ *Pa*
■ – $P = 80$ *Pa*
▲ – $P = 130$ *Pa*
× – $P = 225$ *Pa*
○ – $P = 330$ *Pa*
△ – $P = 500$ *Pa*

hollow effect is insignificant. In this range of distances and at 50–500 Pa pressures the discharge behaves stably. The electric characteristics of plasma-formation change insignificantly.

4. Conclusions

The influence of some constructive discharge system elements on the electric excitation modes and stable maintaining of pulse glow discharge plasma in N_2 in a hollow tube cathode has been investigated. The following discharge system changes have been performed: the position of a hollow electrode-cathode in the dielectric tube-holder; the method of plasma forming gas feeding to the discharge area; the distance between the electrode-cathode and counter-electrode (grounded anode). The investigation has been carried out within 50–700 Pa N_2 pressure range. The obtained results may be used in the design of gas discharge systems with a hollow cathode effect.

Acknowledgements

This research has been supported by the Belarusian State Program of Scientific Research "Science of physical materials, new materials and technologies" assignment 4.1.01.

References

[1] K. A. Shamoo. Effect of nitrogen gas pressure and hollow cathode geometry on the luminous intensity emitted from glow discharge plasma. *American Journal of Modern Physics*, 2(6):276–281, 2013. doi:10.11648/j.ajmp.20130206.11.

[2] E. Sozer, K. Koppisetty, and H. Kirkici. Pulsed hollow cathode discharge characteristics. *Pulsed Power Conference*, 2, 2007. doi:10.1109/PPPS.2007.4345503.

[3] F. Yangyang, J. P. Verboncoeur, A. J. Christlieb, and X. Wang. Transition characteristics of low-pressure discharges in a hollow cathode. *Physics of Plasmas*, 24(Issue 8):083516, 2017. doi:10.1063/1.4997764.

[4] V. V. Budilov, K. N. Ramazanov, Y. G. Khusainov, I. V. Zolotov, and N. S. Babenko. Application of hollow cathode effect for local ion nitriding of machine parts. *Journal of Physics: Conference Series*, 652(1):012052, 2015.

[5] S. Janosi and A. K. Kolozsvary. Controlled hollow cathode effect: New possibilities for heating low-pressure furnaces. *Metal Science and Heat Treatment*, 46(Issue 7-8):310–316, 2004. doi:10.1023/B:MSAT.0000048840.94386.25.

[6] S. F. Brunatto, A. N. Klein, and J. L. R. Muzart. Hollow cathode discharge: application of a deposition treatment in the iron sintering. *Review of Scientific Instruments*, 30(2):145–151, 2008. doi:10.1590/S1678-58782008000200007.

[7] V. I. Gushenets, A. S. Bugaev, E. M. Oks, P. M. Schanin, and A. A. Goncharov. Self-heated hollow cathode discharge system for charged particle sources and plasma generators. *Review of Scientific Instruments*, 81(Issue 6):02B305, 2010. doi:10.1063/1.3258033.

[8] S. Bordusau, S. Madveika, M. Lushakova, and N. Kovalchuk. The influence of microwave cf_4 plasma activation on the characteristics of reactive ion etching of mono-si. *Plasma Physics and Technology*, 4(1):13–16, 2017. doi:10.14311/ppt.2017.1.13.

[9] H. Amemiya and K. Ogawa. Characteristics of a hollow-cathode discharge containing negative ions. *Journal of Physics D: Applied Physics*, 30(5):879. doi:10.1088/0022-3727/30/5/021.

[10] A. R. Petre, M. Bazavan, A. Covlea, V. V. Covlea, and H. Andrei. Characterization of a dc plasma with hollow cathode effect. *Romanian Reports in Phisics*, 56(2):271–276, 2004.

[11] D. Maric, N. Skoro, G. Malovic, Z. L. Petrovic, V. Mihailov, and R. Djulgerova. Hollow cathode discharges: Volt-ampere characteristics and space-time resolved structure of the discharge. *Journal of Physics: Conference Series*, 162(1):012007, 2009. doi:10.1088/1742-6596/162/1/012007.