Low pressure glow discharge in a system with hollow electrode at floating potential

N A Babinov
Department of Electron Devices and Systems, Saint Petersburg Electrotechnical University "LETI", Saint Petersburg, Russia

babinovnikita@gmail.com

Abstract. This article describes the research of the low pressure gas discharge in a system with hollow electrode at the floating potential. The main characteristic features of the discharge distinguishing it from the glow discharge with hollow cathode are described. The studied type of discharge has good perspective to use in the plasma emission systems allowing to reach high current efficiency of the ion sources.

1. Introduction
In the present time devices intended to create beams of fast ions generated in the plasma volume are intensively used for technological processes of surface treatment, coatings deposition and modification. This devices are also known as plasma emission systems. The most common method for plasma generation is to use gas discharges of different types such as arc discharge, glow discharge, inductively coupled discharge etc. The choice of this method is caused by its relatively simplicity, high efficiency and the fact that a gas discharge plasma is well studied.

At the same time, existing in the recent years tendency to reduce an operating pressure during processes of coatings deposition and treatment. This tendency is due to intention to reduce the flow of polluting substances. Moreover increasing requirements to beam quality and uniformity demand study of new gas discharge types that are able to provide the generation of high-density and uniform plasma at the low gas pressure.

One of the promising gas discharge types that are able to provide necessary parameters is a glow discharge with electron electrostatic trapping discussed in details in [1]. At the expense of electron multiply oscillations in the electrostatic trap area the electron path length in the gas discharge area is increased many times. This leads to increasing the proportion of energy that are spent by fast cathode-emitted electrons for gas ionization. This allows significant reducing of the system operation pressure down to the 0.1 and even lower in some cases.

A large number of different emission systems that use the glow discharge with electron electrostatic trapping (in particular, glow discharge with hollow cathode) are known [2, 3]. Such systems operate on direct current and are able to generate ions beams with high density and large cross-section.

At the same time, the systems based on glow discharge with electron electrostatic trapping have some disadvantages. One of the main disadvantages is low current efficiency (the ratio of beam current to the discharge current) of such systems. It is caused by the fact that to ensure the effect of electron electrostatic trapping it is necessary to create a closed cathode structure while the extraction
grid is placed on the one side of the system; the grid area is much smaller than cathode area. Considering that ion current density is practically independent of electrode potential and is equal for grid and cathode; this leads to the fact that extracting beam current is much smaller than discharge current.

There are ion sources designs in which the current efficiency is increased by, for example, magnetic fields using [4]. But even in this case current efficiency in 20–30% is considered high.

For increasing of the current efficiency of plasma emission systems it may be helpful to use the glow discharge with hollow cathode at the floating potential. Due to the zero total current to the isolated electrode in this case all the discharge current is closed through the cathode that plays the role of an extraction grid as well. Thank to this the current efficiency of such system can reach the 90–95%.

In this work the argon gas discharge in the system consisting of three electrodes: hollow cylindrical isolated electrode that was closed from the one side; cathode formed in the shape of disc and placed at the open side of isolated electrode and anode placed outside of hollow electrode.

To ensure the absence of a parasitic discharge in the system and the charges draining from the isolated electrode it was surrounded by the grounded screen placed at the range of about 5 mm. It ensure the absence of parasitic discharge even when the potential of the isolated electrode was greater than 1 kV.

2. Description of experiments

It is known [5, 6] that floating potential of the electrode placed at the path of the electron beam can nonlinearly depend on the energy of the beam electrons. It is associated with the influence of the secondary electron emission phenomenon.

The studied system has the similarities with described in [5, 6] systems in that the isolated electrode is placed at the path of high-energy electrons, in our case they are emitted from the cathode and accelerated in the cathode potential drop.

The significant distinction of the systems is that due to the large area of the isolated electrode, its potential significantly affects the gas discharge plasma configuration, its density and electron temperature; on the other hand the floating potential is affected by the parameters of gas discharge plasma. Moreover, in this work the main attention is given to the discharge with voltage higher than 1 kV and with low current density.

During the experiments the anode of the system was grounded and the cathode voltage was applied to the negative high voltage power supply. The discharge current and voltage as well as potential of the isolated electrode were measured by the analogue and digital instruments; leakage current was not greater than 100 uA.

The measurements were carried out during the burning of gas discharge in argon at the pressure from 3 to 100 Pa. Due to the discharge instability and big influence of the random error, each experiment series was carried out from 3 to 5 times.

One of the experiment series is shown in a figure 1. It can be seen there are two main forms of gas discharge: with high and low potential at the isolated electrode. Transition from one from to another occurs when the discharge current exceeds certain value. Also there is the phenomenon of hysteresis since the revers transition doesn’t occur.

The further experiments allowed to state some assumptions:

1. The low pressure glow discharge with isolated electrode has 2 or 3 forms, significantly that have different values of floating potential.
2. The transition from one form to another occurs when the current exceed certain value, in these moments the visual changes are visible, moreover the discharge voltage changes abruptly.
3. Depending on the form of discharge the voltage of the isolated electrode can take both value of ~20...~40 V, that are typical for floating potential of plasma and the very large negative values close to the cathode potential. This phenomena was not observed in [6] where the floating potential always was significantly lower than electron accelerated voltage.
The strongest differences between the discharge forms are observed when the pressure is low, not greater than 10...20 Pa. When the gas pressure is greater, the differences are slowly erased and then are completely disappear at the pressure of about 50 Pa.

3. Conclusion
The obtained experimental data allows to say the glow discharge with hollow isolated large electrode has some has the characteristic features that distinguish it from other types of gas discharge.

Gas discharge in the described system has much in common with well-studied hollow cathode discharge, although there are significant distinctions. First of all it seems the important role in the occurring processes is played by the secondary electron-electron emission that doesn’t play a big role in the discharge with hollow cathode. Based on the works [5, 6] it can be assumed that it is the secondary electron-electron emission which causes the existence of several forms of gas discharge.

At the same time, the physic processes determining the gas discharge burning are not fully clear. First of all, to compile a satisfactory theory of the discharge with hollow isolated electrode it is necessary to continue experimental work and obtain new data that will allows accurately determining the existing patterns of such gas discharge.

Acknowledgments
This work was performed as a part of the Russian Federation government project assignment №8.2456.2014/K. The research was supported by Department of Electron Devices and Systems of Saint Petersburg Electrotechnical University “LETI.”
References

[1] S N Grygoryev, A S Metel 2007 *Modification of surface by glow discharge with electron electrostating trapping* (Moscow, Moscow State University, 452 p.)

[2] S N Grygoryev, A S Metel A N Isaykov and Yu A Melnik 2005 Har *Hardening Technologies and coatings*. issue 9, pp. 36–40.

[3] Ichiki K., Hatakeyama M. 2008. *J. Phys. D: Appl. Phys.* Vol. 41, p. 024003

[4] S N Grygoryev, A S Metel, Yu A Melnik and V V Panin RU patent № 2373603 Published 20.11.2009

[5] V Ya Martens 1996 *Journal of tech. physics* Vol. 66, issue 6, pp. 70–76

[6] N V Gavrilov, A I Menshakov, A S Kamenetskiih 2013 *Journal of tech. physics* Vol. 83 issue 1, pp. 74–79