Formation of Low-Energy Ion Flows in Modified Penning System with Nonequipotential Cathode[1]

S.P. Nikulin, D.F. Chichigin, P.V. Tretnikov*

Institute of Electrophysics UD RAS, 106 Amundsena street, Ekaterinburg, 620016, Russia,
Phone:(343)2678829, Fax:(343)2678778, E-mail: nikulin@iep.uran.ru
** Ural State Technical University - UPI, 19 Mir street, Ekaterinburg, 620002, Russia*

Abstract – The opportunity of generation of low - energy ion flows in case of acceleration of the particles in the cathode sheath of one of the end cathodes of Penning system was studied. The acceleration up to required energy (1–2 keV) was ensured with an accelerating voltage supply connected between the anode of the system and this cathode element which played the role of a treated detail. The other end cathode was parted into a ring and a control electrode. The control electrode was under floating potential, and due to this the generated plasma was close to uniform one in the larger part of the discharge system that in turn ensured uniform current density distribution on the treated detail. The discharge power supply was connected between the ring cathode and anode, and the current to the treated detail varied proportionally to the discharge current. Independent adjustment of the target current and energy of ions thus was ensured which is difficult in systems based on high-voltage glow discharge. Besides, the working pressure in our system based on the Penning discharge with nonequipotential cathode is of some orders lower (~ 1 mTorr), than in high-voltage glow discharge, that makes perspective its application for ion cleaning or etching.

1. Introduction

Ion beams with energy of particles of 1–2 keV find a use in different processes of ion technology, for example for surface cleaning or etching. Three-electrode accelerating – decelerating ion optics are usually used for formation of such beams. The ion optics are the most complicated and least reliable element of ion sources. It is explained, in particular, by high thermal loading on first emitter electrode contacting directly to plasma generated in the discharge system of the ion sources. An inadmissibility of thermal overloads and also low perveans of the ion optics impede achievement of high ion current density and lead to increase in time of processing.

The higher current can be reached in the case of acceleration of ions directly in the cathode sheath, that is realised, for example, in systems based on high-voltage glow discharge, where the treated detail plays the role of the cathode. However, these systems are not of wide application because rather high pressure unacceptable for many processes of ion – plasma technologies is required for maintaining of the discharge. Besides, the basic characteristics of the discharge such as current and voltage are interconnected that impedes adjustment of parameters of the ion beam.

The working pressure (~ 1 mTorr) in system based on Penning discharge is of some orders lower than in systems on the basis of the high-voltage glow discharge. Besides, the experiments, carried out earlier, show that the stable operation of the Penning discharge is possible, when different cathode elements are at different potentials [1]. This circumstance was used for control of radial distribution of plasma concentration and obtaining of uniform ion current density. The results, introduced in the present work, show that the above circumstance can be used for independent adjustment of such parameters of ion flow as current density and energy of particles in Penning system, in which the treated detail plays a role of one of the end cathodes.

2. Scheme and Results of Experiment

The electrode system used in experiments is presented schematically in Fig. 1. Height and diameter of the discharge chamber are equal to 150 mm. The end cathode 6 in the given situation fulfilled the role of the treated detail, and the acceleration of ions was carried out in the region of the cathode voltage drop formed near it. The adjustment of ion energy was ensured with an accelerating voltage supply (AVS), connected between the anode 4 and this end cathode. The energy of particles corresponds to the supplied voltage because plasma potential is close to one of the anode that is characteristic feature of high-current regime of glow discharge with oscillating electrons.

The adjustment of ion current to the treated detail was realized by discharge power supply (DPS) connected between the anode and a ring cathode 1 located on the other end of the system. The circumstance used here was the following: the values of ion currents to

[1] The work was supported by Russian Fond of Fundamental Investigation (No. 02-02-17860) and Russian Science Support Foundation.

both ends of the discharge system are equal to each other, so magnification of the discharge current Id leads "automatically" to increase in the current *I* to the treated detail.

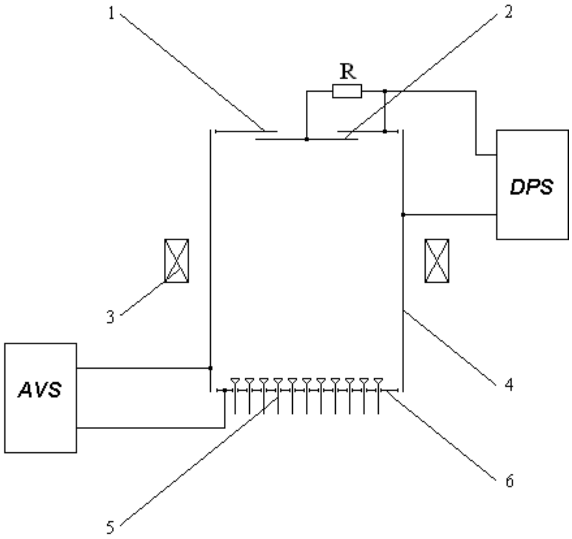

Fig. 1. Electrode system: 1 – ring cathode, 2 – control electrode, 3 – solenoid, 4 – anode, 5 – system of probes, 6 – end cathode (treated detail), DPS – discharge power supply, AVS – accelerating voltage supply

A control electrode 3 was used for generation of uniform plasma [1]. In the present operation we used the electrode with 30 mm diameter. It was connected to the discharge power supply through a high-ohmic resistor. We used here the earlier obtained result according to which the optimum value of potential of the electrode is close to floating one when using the control electrode with such size. Such value of potential was considered as optimum one when the radial profile of plasma was close to uniform one in the larger part of the discharge chamber. The measurements of the radial profile of the ion current were carried out with the help of a system of probes 5.

The working gas (argon) was filled into the discharge chamber through a central hole in the control electrode. The magnetic field was created by a solenoid 3.

It has been revealed that the increase in the accelerating voltage U_a does not disturb stability of the discharge. The operation voltage of the discharge U_d being measured between the anode and the peripheral ring even was reduced (see Fig. 2). Apparently, it is explained by occurrence of electrons on the ring cathode not only owing to ion – electron emission but also due to secondary electron – electron emission caused by electrons emitted from the treated detail.

The energy efficiency defined as $\alpha_e = I/I_d U_d$ is order of magnitude more than the value achieved when using ion optics and can reach 2–3 A/kW. It is explained by the fact that all ion current going to one of the ends of the system is used for treating the detail and also by the use, though not direct, of electrons emitted from the target. It is necessary to note that the current of the end cathode playing the role of the target increased with magnification of the accelerating voltage and exceeded the discharge current by some percent (see Fig. 3). Apparently, it is explained by increase in coefficient of ion – electron emission.

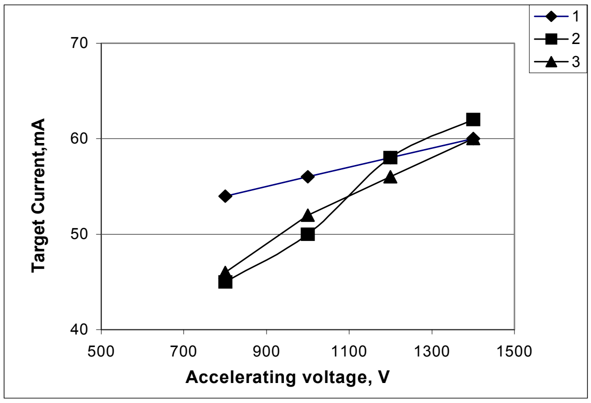

Fig. 2. Discharge voltage against accelerating voltage. $Q = 0.2$ cm^3/c, I_d = 40 mA. 1 – B = 8.4 mT, 2 – B = 11.2 mT

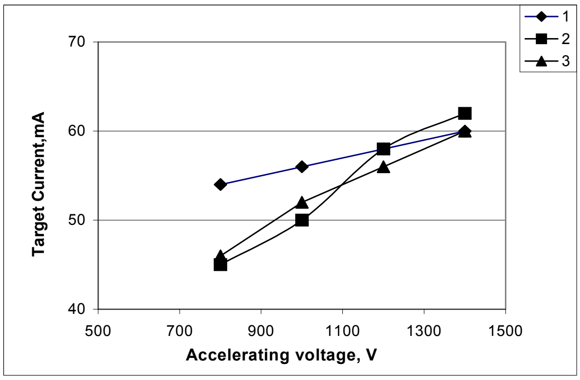

Fig. 3. Dependence of current to the treated detail on accel erating voltage. $Q = 0.2$ cm^3/c. 1 – B = 11.2 mT, I_d = 50 mA, 2 – B = 8.4 mT, I_d = 40 mA, 3 – B = 11.2 mT, I_d = 40 mA

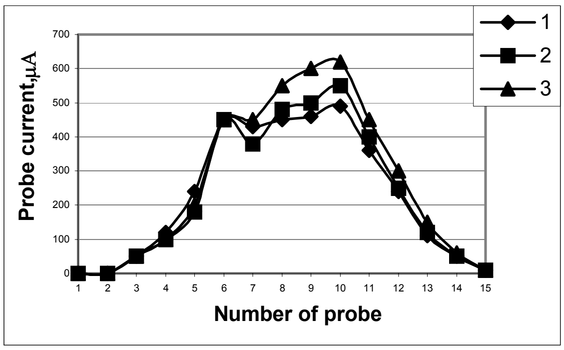

Fig. 4. Radial distribution of ion current. Q = 0,2 cm3/c, B = 11.2 mT, I_d = 40 mA, U_a (V): 1 – 600, 2 – 1000, 3 – 1400

Essential contortion of the radial profile of ion current was not observed with magnification of the accelerating voltage (Figs. 4, 5). Measurements of the radial distributions were carried out also in different magnetic fields. No significant diversion from uniformity was revealed (see Fig. 6). It should be noted that large-scale low-frequency (10^4 Hz) instability arises in Penning system in strong magnetic fields, which gives to practically 100% modulation of ion current density.

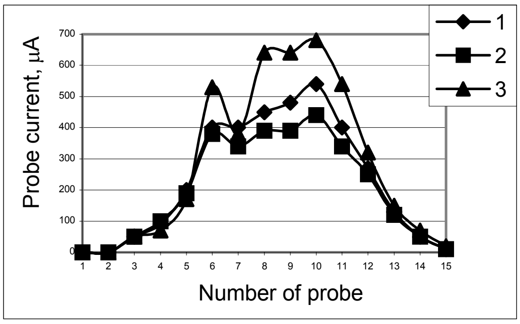

Fig. 5. Radial distribution of ion current. Q = 0.2 cm^3/c, B = 14 mT, I_d = 40 mA, U_a (V): 1 – 600, 2 – 1000, 3 – 1400

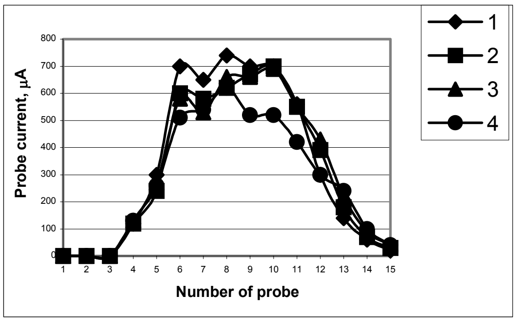

Fig. 6. Radial distribution of ion current at different magnetic fields. Q = 0.2 cm^3/c, U_a = 1000 V, I_d = 50 mA. B (mT): 1 – 14; 2 – 12.6; 3 – 11.2; 4 – 9.8

The operation of ion optics is impossible in such mode, but the mode with plasma instability can be used in the case of acceleration of ions directly in the cathode sheath. Thus, operating range of magnetic fields can be expanded.

3. Conclusion

The results of the carried out investigations show perspectivity of the use of Penning discharge with non-equipotential cathode in systems of ion cleaning and etching. The energy efficiency can be enlarged up to 2–3 A/kW when ions are accelerated in the cathode sheath of one of the end cathode which plays the role of the treated detail. This value is one order of magnitude more than the value achieved when using ion optics. It is stipulated by the use of secondary electrons emitted from the surface of the treated detail for maintaining the discharge. In viewed system these electrons bombard the surface of the opposite end electrode and cause effective secondary electron – electron emission. Increased (1–2 kV) voltage applied to the end cathode does not disturb stability of the discharge and uniformity of plasma.

References

[1] S.P. Nikulin, D.F. Chichigin, V.V. Hiller, P.V. Tretnikov, *in: Proc. 6th Int. Conf. on Modification of Materials with Particle Beams and Plasma Flows*, 2002, pp. 132–1355.