Technological Wide-Aperture Source of Gas Ions

Yu.N. Paraev, V.P. Yanovskii

Institute of Strength Physics and Materials Science SB RAS,
2/1, Akademicheskii av., Tomsk, Russia, 634021, fax: 7 3822 49 10 32,
E-mail: techimpl@mail.tomsknet.ru

Abstract – The gas ion source with energy of 30 keV, ion current up to 20 mA, ion beam of 480 mm in diameter and 500 mm in distance from last electrode was presented in work. Ar, N_2 as plasma-forming gases were used in source. In the paper the ion source configuration was described where the source was used as ion emitter with closed Hall's current. The results of volt-ampere investigation and operating capability were carried out.

1. Introduction

The main problem of the plasma cathode producing of the sources with wide-aperture of ion beam is related to surface emission formation of the plasma cathode and a power costs. There are different design concepts of ion sources adequate the technological requirements. Basic task of this paper was producing of the wide-aperture high-energy gas ion source simple in operation and design, which is capable to work in conditions of large gas capacities.

2. Experimental Details

The scheme of ion source is shown in Fig. 1. The operation of ion source is based on the usage of main and auxiliary discharges. There are two discharge systems in this design. The discharge with closed Hall's current is applied as a auxiliary discharge in crossed fields of E×H, which is described in detail in [1, 2]. In this scheme of ion sources 1 is the body of equipment, 2 and 3 are welding rods (cathode) and 4 is welding rod (anode). A body 1 and the welding rods 2, 3 are the magnetic conductor of the magnet system of auxiliary discharge source. The magnetic field is formed in gap, formed by welding rods 2, 3 using permanent magnets 5 with magnetic induction about 0,1 T. One of advantages of the ion accelerators with a closed electron drift is a small ion beam angle. In this case the ion accelerator should be to form the ion beam with an enough large angle to receive the uniform distribution of the ion flow on the frontier of the main discharge plasma cathode. For this purpose the inhomogeneous electrical and magnetic fields are formed in the discharge gap and in the channel of ions acceleration. The field non-uniformity is presetted by the anode spherical configuration and the welding rods 2, 3 that of magnet systems guaranteeing the diverging magnetic channel of the ions output. The geometrical parameters of an auxiliary discharge system is selected so that size of the ion beam achieved given beam size on the target 9.

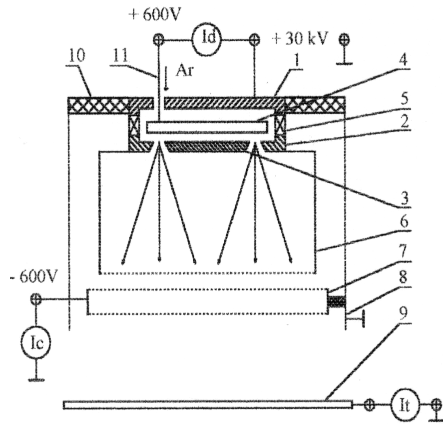

Fig. 1. The scheme of ion source

The main discharge is formed by the hollow cathode 6 and welding rod 7. Discharge gap between welding rods 6 and 7 was selected experimentally so that there was voltage breakdown at accelerating voltage 30 kV and working pressure up to 0.15 Pa and was equal 28 mm. The welding rod 6 is made as cylinder 230 mm in diameter and 170 mm in altitude. The mesh with a transparency by ~ 80% is established at the electrode end. The welding rod 7 was made as cylinder 260 mm in diameter and 40 mm in altitude. At cylinder ends the molybdenum wire having 0.4 mm in diameter was attached for obtaining of the transparency not less than 95%. This configuration of a welding rod – grid 7 allows to use it as the effective trap for the secondary electrons.

The electrical decoupling of the electrode system is carried out using kapron isolator as a flange. The electric strength of isolator design was 40 kV. The cooling of a body 1 and welding rods 11 is made using radiators blown by the ventilator. The welding rods 11 retain the anode of an auxiliary discharge system and simultaneously they are channels for letting-to-gas in discharge area. On welding rods 11 the chamber of pressure equalization of working gas was built, which provides the constant gas injection in the auxiliary discharge area.

All source welding rods are made from a non-magnetic stainless steel. The magnetic circuit of an auxiliary discharge system is made with soft-magnetic alloy.

Principle of source operation is following.

The discharge in crossed E×H fields is fired on the welding rod 11 at an energizing of ~ 600 V in the discharge gap the anode – cathode of discharge system. The discharge ions go out in the hollow cathode and form emission surface 230 mm in diameter on the grit frontier. At supply of accelerating voltage ~ 30 kV the ions come out from the hollow cathode plasma and they accelerate to the target between the hollow cathode 6 and grid of the secondary electrons suppressing 7. The accelerated ions beam comes to the target with 30° in divergence. The beam divergence is determined by initial rates vectors, which have gained ions in the distorted E×H field. The beam divergence is proportional to welding rods geometry of the auxiliary discharge system. The activity of acceleration with the closed electron drift is described in detail in [1]. The main advantages of this source are the ions high-density in gas discharge at small power costs, the obtaining of wide-aperture cathodes of discharge system, the low heating of an electrode system.

3. Results and Discussion

The experimental volt-ampere characteristic (VAC) of ions source as a function of the working gas pressure are shown in Figs. 2, 3, 4, 5. The scheme of measurements of VAC is shown in Fig. 1. The dependences of the discharge current (I_d) of an auxiliary discharge system, the grid current (I_n) of the secondary electrons suppression and the target (I_t) current in the accelerating voltages range of ions 0 … 30 kV and the Ar gas pressure of 0.04 … 0.12 Pa were measured.

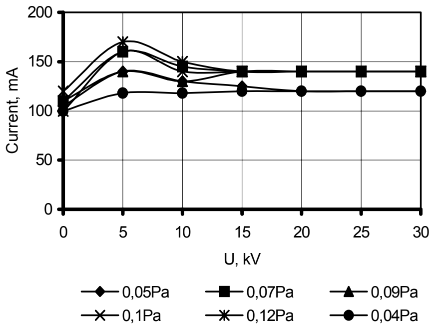

Fig. 2. The discharge current as function of the accelerating voltage at different pressure of Ar

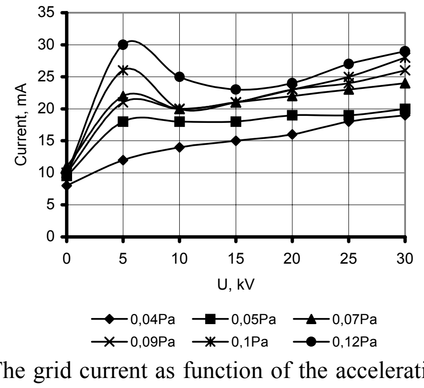

Fig. 3. The grid current as function of the accelerating voltage at the Ar different pressure

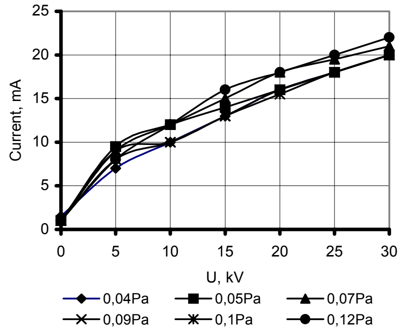

Fig. 4. The target current as function of the accelerating voltage at the Ar different pressure

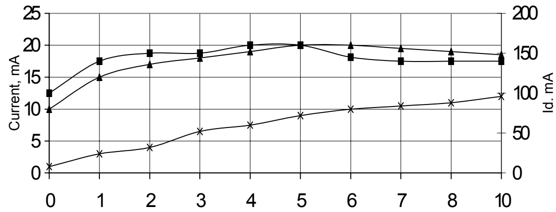

Fig. 5. The volt-ampere characteristic of the ions source at the Ar different pressure

Specific feature of these dependencies is the anomalous increase of currents I_d, I_g at accelerating voltage about 5 kV. When the accelerating voltage increases up to 10 … 15 kV the currents I_d and I_g decreases and then there is stabilization of I_d and minor increase of I_g currents. At the same time I_t smoothly changes with the accelerating voltage and gentle depends on gas pressure in investigated range. The anomalous increase of the I_d and I_g currents confirms more precise measurement of dependencies I_d, I_g and I_t in the accelerating voltage range 0 … 10 kV at pressure of 0.07 Pa.

The VAC dependencies of I_d and I_g are not studied finally. It is possible to suspect, that the anomalous volt-ampere characteristic change of I_d and I_c are related to the features of the closed electron drift acceleration without the self-maintained discharge duty compensator [1], and also with his usage at discharge voltage less 1 kV [3]. As for the I_t VAC (Fig. 4), the nature of its change is related to the ions exit on the flash chamber. It is typical the low ions drift on the flash chamber for the acceleration with the closed electron discharge. It means, that the output current should be close to the discharge one. In investigated source the discharge current exceeds a grid summed current and target ~ 3 times. Apparently, it can be connected with features of activity of acceleration with the closed electron drift in self-maintained discharge duty and the imperfection of the discharge chamber design. But, despite of it, for the investigated design of the ions source the use factor of ions was obtained within the limits by 15 … 17%, which one has high value in comparison with electrostatic plasma sources with similar parameters [4]. In experiments the measurements of the ions beam density distribution on the target-to-substrate distance 400, 500, 600 mm from suppression grid of the secondary electrons were carried out. The measurements were carried out according to the paper black-out from of ions beam. For the given ions source design there is dependence between the ions beam distribution and the distance to measured section. The best current density uniformity was achieved ~ 500 mm in distance, in this case the distribution gradient of the current density was ~ 15% with 480 mm in diameter in the investigated pressure range of working gas.

The thermal regime keeping is very important task for this ions source. The electrode heating should not be higher 800 °C since the rubber vacuum seals are used in the ions source design. The temperature measurements in the hottest ions location of the ions source (body and magnetic circuit of an auxiliary discharge system) were made to select the electrodes cooling system. The temperature measurement carried out at the ions energy of 30 kV, ions currents on the target was 20 mA and grid 22 mA, discharge current was 180 mA, dissipated power of the discharge system was 60 W. Usually two types of grid 7 (Fig. 1) were used. It is the wire with 1.2 mm and 0.4 mm in diameter.

The electrodes cooling carried out using the radiators blown by air. The experiments have shown that the basic contribution to the electrodes heating of an auxiliary discharge system is introduced by secondary electrons from the first electrode grid depress of the secondary electrons. At identical dissipated power (~ 60 W) in discharge the heating of ions source is higher when the wire is used grid 1.2 mm in diameter.

The ions source burn-time was 40 min before the beginning of the voltage breakdowns due to the rubber joints overheating. The trouble-free operation source time did not limit by the electrode overheating at usage of a grid with the wire 0.4 mm in diameter.

The electrode heating temperature was stabilized for the first source operating hours and did not exceed 65 °C for a long time of continuous operations. In experiments the time of the source continuous operation achieved 8 hours at accelerating voltage –30 kV, discharge current –180 mA, grid current 22 mA, target current was 20 mA and gas pressure was 0.05 Pa.

The ions source characteristics:

– energy of ions is up to 30 keV,
– the ions beam current is up to 20 mA,
– the ions beam aperture is 480 mm,
– the current density non-uniformity of ions on section is ~ 15 %,
– discharge dissipated power is up to 60 W,
– operating pressure range is 0.04 … 0.12 Pa,
– working gas is argon or nitrogen,
– cooling is air forced,
– total dimensions: height is 400 mm,
diameter is 360 mm.

4. Conclusion

The results of the ions source investigation demonstrate that the plasma acceleration with closed electron drift is perspective as the ions emitter at designing of the wide-aperture high energy ions sources due to some reasons. First, the design is simplified, the reliability and also economy are improved Second, there is a capability without principled limitations to receive any in reasonable limits the ion beams sizes with the ionic density uniform distribution on the required ions source length.

The gas ions designed source can be applied to the solution of a physical and technological problems in the different branches of science and engineering.

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