Quasiribbon Vacuum Arc Ion Source "Raduga-6"

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Abstract – The results on research and development of new modification of a high-current quasiribbon repetitively-pulsed ion and plasma source "Raduga-6" on the basis of extended vacuum-arc evaporator generating plasma by a dc vacuum-arc are presented in the article. A new modification of a time-of-flight extended plasma filter was developed and used for metal plasma filtering from microparticle fraction. Research and development of a model of extended vacuum-arc evaporator and plasma filter adapted for it have been described.

1. Introduction

The majority of ion sources of metal ions have the area of an ion beam of the order of 300 $см^2$. Application of implanters with such area of ion beam cross-section for an even processing of products of sufficiently greater size is ineffective.

Unlike repetitively-pulsed metal ion sources on the basis of a pulsed vacuum arc [1–5] in the ion source "Raduga-5" the dc vacuum-arc discharge with plasma filtering from microparticle fraction is used for metal plasma generation [6]. Application of a dc vacuum arc opens the prospects for the development of metal ion sources with significant ion beam sizes.

A new modification of a high-current vacuum-arc ion source "Raduga-6" with quasiribbon ion beam on the basis of extended vacuum-arc evaporator and the plasma filter adapted for it has been described in this paper.

2. Experimental setup

The scheme of a quasiribbon vacuum-arc ion source "Raduga-6" is presented in Fig. 1.

Continuous plasma generation is realized in a discharge gap formed by the hollow anode *1* and the cathode *2* of the extended arc evaporator. Discharge stabilization and cathode spots confinement on a face surface of the cooled cathode is realized due to creation of a two-arch magnetic field of a magnetron type *3*. In a final variant the magnetic system has been executed on constant magnets. The electromagnetic coil has been used in the experiments for the convenience of a quick change of magnetic field characteristics.

New modification of the extended plasma filter (PF) has been developed for the metal plasma filtering from microparticle fraction. The regime of ion beam formation in the source is realized as a result of a repetitively-pulsed formation of an accelerating voltage in the diode formed by the net electrode *5* and the "grounded" net electrode *6*. The additional grid *7* under a negative potential is provided in the source design for the plasma electrons cutoff from the accelerating gap.

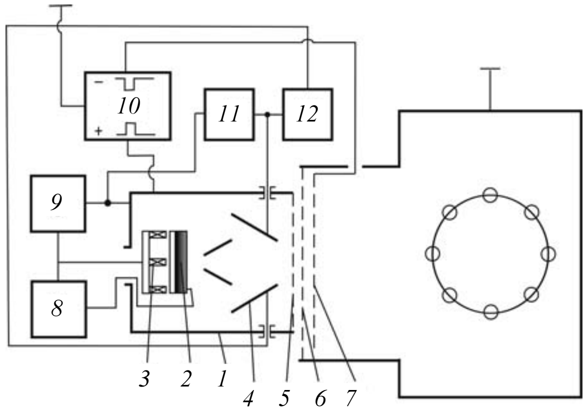

Fig. 1. The scheme of a quasiribbon vacuum-arc ion source "Raduga-6": *1* – anode; *2* – water-cooled cathode; *3* – magnetic system; *4* – PF; *5* – grid electrode expander; *6* – "grounded" grid electrode; *7* – additional grid electrode; *8* – pulse power supply of the igniting electrode; *9* – power supply of the vacuum arc evaporator; *10* – pulse power supply of an accelerating voltage; *11* – power supply of plasma potential on PF; *12* – power supply of the plasma filter

3. Vacuum arc metal plasma generator

The construction in the form of an extended plate with a thickness of 1 cm, width of 10 cm and length of 60 cm has been chosen as an extended vacuum-arc evaporator. The back part of a plate has been cooled by water for heat removal during the arc evaporator operation. The two-arch magnetic field in the experiments was created by a "ш"-like magnetic conductor and the electromagnetic coil located on the central core of the magnetic conductor. The igniting electrode with a ceramic insert has been placed on the cathode surface near the trajectory of a cathode spot movement, but outside the erosion zone. When carrying out the research on plasma generation and measuring the discharge characteristics, the water-cooled anode *1*, by its form repeating the cathode perimeter with width between extended walls equal 140 mm was used. The anode was located on distance of 60 mm from the cathode surface.

Considering a question of a new type ion source development it is important to know the regularities of cathode spots movement in the given design of an extended vacuum-arc evaporator depending on the value of magnetic field strength and the cathode material. The experiments carried out have shown that the velocity of a cathode spot movement is different for different cathode materials and changes depending on the magnetic field intensity. Experimental data are presented in Fig. 2.

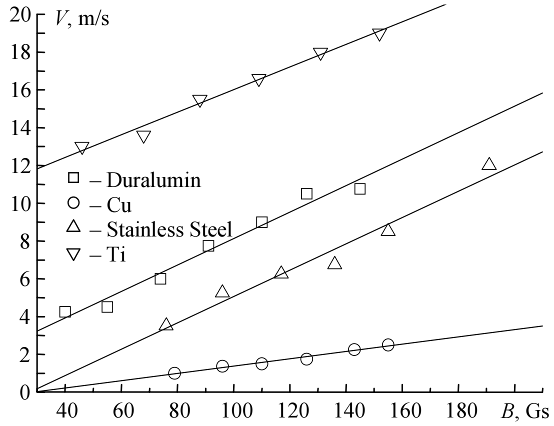

Fig. 2. Velocity of the cathode spot movement depending on the magnetic field strength created on a face cathode surface and the cathode material

The obtained data show that a certain velocity of cathode spot movement is characteristic for each cathode material, for example at the same value of a magnetic field equal 100 Gs for Ti, duralumin, stainless steel, and Cu, the velocity of a cathode spot movement has made 16.2, 8.2, 5, and 1.5 m/s accordingly. Further in the paper the substantiation will be given, why it is fundamentally important for a source the "Raduga-6" to know the velocity of a cathode spot movement depending on a used material and the value of a magnetic field intensity.

It is obvious, that the operation efficiency of any ion source is defined in many respects by the efficiency of a plasma flow using. In this connection, the investigations of regularities of change in ion-emission properties of an extended vacuum-arc metal plasma generator for different materials depending on the intensity of a magnetic field created on the cathode-working surface have been carried out. A collector with an area of 40×20 cm has been used in the experiments to measure the ion saturation current from plasma. The collector was located parallel to the cathode surface on the distance of 23 cm. A negative potential (–100 V) was supplied on the collector to cut-off the plasma electrons. Fig. 3 shows the data on the change of the ion saturation current from plasma for different cathode materials depending on the value of the magnetic field intensity on the cathode surface at initial arc current of 145 A.

It follows from the presented data, that the increase in intensity of the magnetic field leads to decrease of the registered ion current and consequently to reduction of emission characteristics of the plasma generator. The most optimal values of the intensity of magnetic field created on the cathode surface make 40–70 Gs.

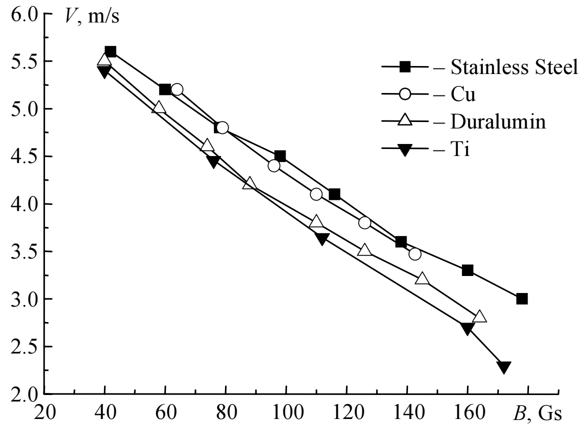

Fig. 3. Dependence of the ion saturation current from plasma for the cathodes of Ti, duralumin, stainless steel, and Cu on the value of intensity of the magnetic field

At that, stable operation of the vacuum-arc evaporator is observed and the greatest ion saturation current from plasma exceeding 3% from the arc current is reached. Taking into account a sufficient distance from the cathode surface to the ion collector and small angular domain (with general 180° expansion of the plasma flow), the obtained results seem quite optimistic not only for creation of the ion source but also for the development of extended vacuum-arc metal plasma generators.

4. Plasma filter

The plasma filter in the metal plasma ion source is a fundamental element as without the plasma flow filtering, the ion flow will contain a sufficient part of microparticle fraction, which will dust the treated surface during a short time and realization of ion assisting and ion implantation in such conditions can not be useful.

Our work experience on the arc evaporator plasma filtering from microparticle fraction [6], enabled to develop and adapt the PF of special construction applicable to the extended vacuum-arc evaporator with the two-arch magnetic field generating cathode spots from two emission areas. Plasma filter presents an optically opaque system of rectilinear electrodes bended under a certain angle to the cathode surface as shown in Fig. 1. A positive bias potential is applied to the filter electrodes relatively to the anode. The electric current transmission along the plasma filter shutters forms a magnetic field around them, which partially magnetizes plasma electrons.

The investigations carried out with the extended PF, which results are presented in Fig. 4, show that at certain regimes of the vacuum-arc evaporator and PF operation, the ion saturation current from plasma reaches 1.8 A and this satisfies to the conditions of the ion source development. The availability of an erosion-free zone on the cathode surface as well as magnetic insulation of the cathode and PF enabled to approach the PF central electrodes to the distance of 5 cm from the cathode surface. With such distance, the influence of PF magnetic field on the conditions of plasma generation on the cathode occurred in the experiments. When PF magnetic field is opposite in direction to the magnetic field of the vacuum-arc evaporator (Fig. 4), with the increase of the current flowing along PF electrodes to 470 A, maximum of the ion current registered on the PF output is observed, and then, with the further current increase, a sufficient ion current decrease is observed. It is explained by the fact that the PF electrodes are located near the cathode surface and by the principle of superposition of magnetic fields at increase of the current flowing along the electrodes up to 470 A, the decrease of initial strength of the magnetic field occurs on the cathode surface, thus increasing the registered ion current. Further increase in the current flowing along the PF electrodes leads to a greater decrease in magnetic field strength on the cathode surface and unstable discharge burning. At that the sharp decrease of the ion current on the output of the system occurs. This mechanism has been proved by the experiment when the initial magnetic field created on the cathode surface increased up to 112 Gs. In this case with the increase of the current flowing along the PF electrodes to obtain the maximal value of the ion current, a greater current on the PF electrodes (725 A) is needed to compensate the initial value of the cathode magnetic field strength. The maximal registered ion current made 1.3 A.

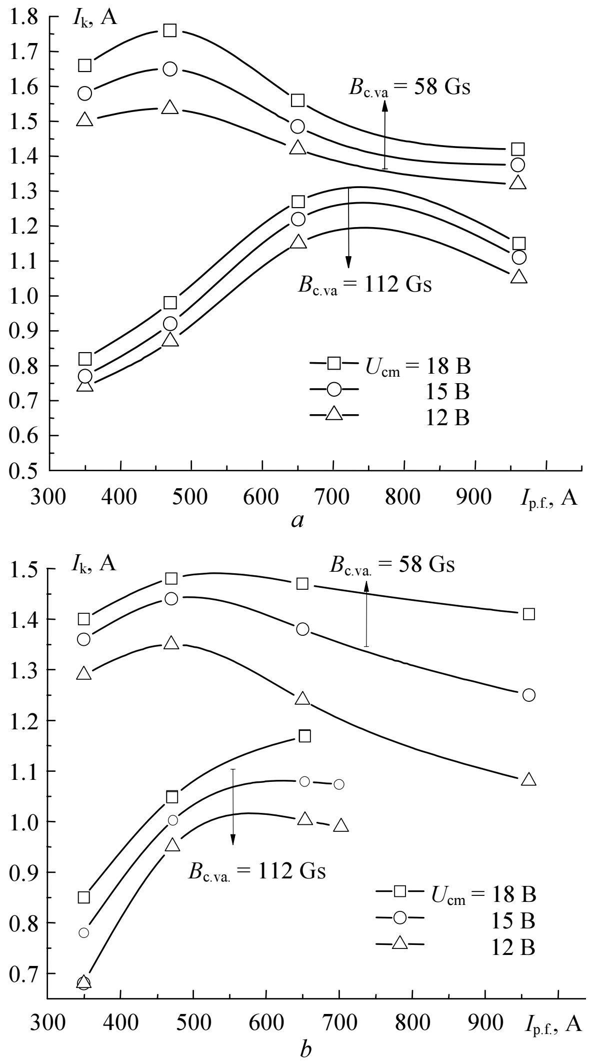

Fig. 4. Dependence of the collector current I_k change on the current flowing along the PF electrodes $I_{p.f.}$ and bias potential supplied on the PF electrodes: *a* – magnetic field of PF is opposite in direction to the magnetic field created on the cathode surface; *b* – magnetic field of PF is codirectional to the magnetic field created on the cathode surface

Fig. 4, *b* presents the data on ion-emission properties of vacuum-arc evaporator, when the magnetic field of PF coincides in direction with the magnetic field on the cathode surface.

With the same direction of the magnetic fields the maximal value of the ion current is 23% less for the initial value of the magnetic field strength created on the surface of the cathode equal to 58 Gs. The increase in the value of the current flowing along the filter electrodes does not lead to any considerable changes in the ion current. With the increase in the initial value of the cathode magnetic field strength to 112 Gs, a sharp decrease of the ion current in comparison with the oppositely directed magnetic field occurs and with the current flowing along the PF electrodes and equal to 670 A the plasma generation instability occurs.

5. The ion beam formation

When developing an accelerating system for the ion source of the ribbon ion beam "Raduga-6", it is essential to reach high homogeneity of the ion current density along the whole beam. It can be easily realized in case of application of a dc accelerating voltage. In this case the ion beam will be formed in the plasma generation area by the cathode spot. However, the ion beam power in this case with the current of about 2 A and accelerating voltage of 40 kV will make about 80 kW. The possibility of the power control in the ion beam is based on repetitively-pulsed formation of the ion beam at dc plasma generation by the cathode spot [6]. In the ion source "Raduga-6" it was important to use desynchronization of the cyclic frequency of the closed movement of the cathode spot of the extended vacuum arc evaporator and the accelerating pulse repetition rate in order to obtain homogeneous quasiribbon ion beam.

In the chosen design of the vacuum-arc evaporator with the two-arc magnetic field, the cathode generation occurs in the local area occupying about 10–15% of the whole surface. That is why the decrease in ion-emission characteristics occurs after a while. A system of displacement of the cooled cathode in the cross direction with fixed position of the two-arc magnetic field and PF has been used to prevent from such effect in the quasiribbon vacuum-arc ion metal source "Raduga-6". The application of the displacement system allowed obtaining the greatest cathode erosion and preserving the emission properties of the arc evaporator cathode.

6. Conclusions

The developed quasiribbon vacuum arc ion source "Raduga-6" has the following parameters: the extended ion beam with the length of 60 cm, with the discharge current of 145 A, the ion beam current makes 1.5 A, the accelerating voltage 20–40 kV, accelerating pulse duration 400 µs, pulse repetition rate up to 200 pps, ion beam power in the repetitively-pulsed regime at maximal pulse repetition rate reaches 5 kW.

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