Investigation of Filament Operating Mode Influence on Discharge within E×H Fields

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Abstract – The discharge has been ignited within crossing electric and magnetic fields in the ion source with double anodes. There are two electromagnets and three-pole magnetic system allowing flexible control of the value of magnetic integral in the discharge area.

The filament current influence on the discharge parameters under the different magnetic field configurations was investigated. The features of discharge ignition and the neutralization of space charge at different values and directions of magnetic flux lines were discovered. The ampere-voltage characteristics and the ability of the increase of power discharge more than 2 times at certain magnetic field configuration were established. The optimal operating modes of filament for obtaining high current low energy ion beam were determined.

1. Introduction

Study of the intensification of a discharge in crossed electric and magnetic fields as well as neutralization of a space charge of the intensive ion beams are stimulating by the variety of their application in science and technology [1, 2]. The ion-beam methods are rapidly developing for the realization of the novel technology of material processing. These approaches allow independently from the substrate, flexibly and on-the-fly to control the process parameters in contrast to plasma methods [3, 4]. The implementation of ion-assisted deposition processes requests the use of the intensive low energy (up to 300 eV) ion flows. However, it is known that for ignition and creation of the discharges in crossed electrical and magnetic fields generating such beams, and for neutralization of a positive space charge, additional injection of electrons is needed. The question of the current compensation at interaction ion beam with the surface of electrically non-, semi- or poorly conducting and polymers substrates is technological important. Build-up of positive charge leads to the limitation of application area of these methods in consequence of appearance of an induced discharge on the workpiece surface and breakdown of thin dielectric layers [5]. The process rate decreases due to appearance of reflected ions [3].

Neutralization of a positive space charge of the ion beam can be obtained by the secondary electrons appearance as a result of transportation and if their additional an injection is existing.

The thermoionic emission from heated tungsten or tantalum wire is well known method for electron emitting. Although filaments obviously have problems at working with reactive gases [3], this is simple device. It allows to generate power low energy discharge and at the same time to neutralize ion beams with current over 1 A.

The filament are used for complete a compensation of the plasma's charge of the beam at transportation with the purpose decreasing it potential which is defining the level of the space charge compensation.

2. Experimental Setup

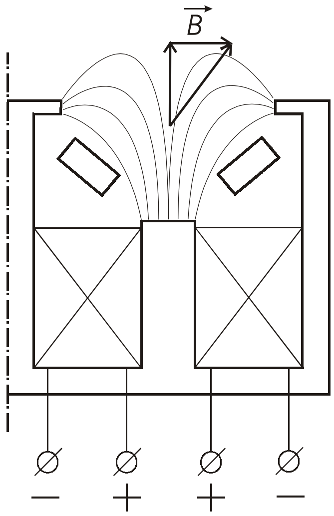
Investigation was carried out on the experimental setup equipped with the ion source with the double anode and a discharge in crossed electric and magnetic fields [6]. There is a three-pole magnetic system with two independent field sources which permits controlling the axial and radial components of the magnetic field.

Two electromagnets were located coaxial inside a magnetic circuit and were used as sources of a magnetic field. Each of them connected up to independent power supply, one of which has possibility reverse switch-on. Among the electromagnets there is the ring-shape pole. The anodic system consists of two concentrically located anodes in area, between which taking place an ionization and acceleration of ions. Outside of accelerating system was fixed the cathode-filament.

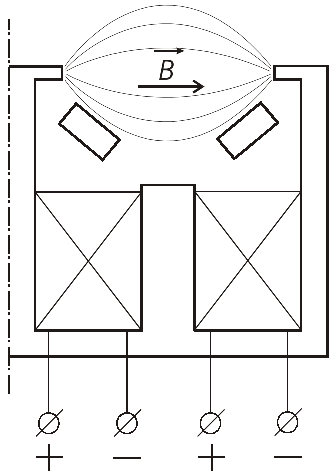
Depending on the mode of operation of the ion-plasma system, the electromagnets switch on in the "counter" (Fig. 1a) or "forward" (Fig. 1b) direction of electric current in the windings, which permits controlling the magnetic field shape in the region of ionization and acceleration of ions.

In the case of "counter" switching of electromagnet voltages, a magnetic field with a significant axial component is formed and the source generates a low-energy ion beam (30–450 eV). If it is necessary to form an ion beam with higher energies (up to 1 keV), "forward" current is applied to the electromagnets and in the discharge region a radial magnetic field is formed.

The ion source was cooled by three water contours – the separate cooling of anodes through the water coils, on which the corresponding voltage are applied, and magnetic circuit under the vacuum chamber potential.



a



b

Fig. 1. Form of the magnetic field in the discharge at “counter” (a) or “forward” (b) switch-on of electromagnet voltage

Ion beam diameter 120 mm spreads in the chamber with metal walls under the ground potential. The cathode of the ion source also was ground. The discharge voltage was measured relative to the chamber walls.

The working gas (argon) feeds in the ion source through the needle leak and has controlling by the thermo-resistivity flowmeter. Working pressure in chamber was $4 \cdot 10^{-2}$ Pa. The filament-cathode consist of two series connected tungsten wires of diameter 0,4 mm and length 80 mm each. It was located at the border of ion beam. The filament power supply unit has 50 V, 30 A.

3. Results and Discussion

In papers [6] was established that a considerable influence on the discharge parameters and the forming of the ion beam have the current-ratio coefficient of the solenoids $K_s = I_1/I_2$. I_1, I_2 – currents applied to the external and internal electromagnets, respectively.

In this paper are presented results of experimental research the influence of the cathode-filament current on a voltage, a current and a power of the discharge at the diverse configuration of the magnetic field.

Vertical and radial components of the magnetic flux in the accelerating channel of an ion source at the different values K_s have varied from 3 up to 35 mT. There is a appreciable anisotropy of the magnetic field distribution within the volume of the discharge region at the number an appointed K_s.

The influence of filament current on the discharge parameters is weak when radial component of flux density on a middle diameter of the discharge’s channel more than 15 mT at the shape of the magnetic field shown in Fig. 1b. Under smaller values of a magnetic field the discharge current is restricted to 2–3 A, the considerable instabilities of the discharge arise and develop.

In the case of “counter” switching of electromagnets depending on K_s three basic dependences of the discharge characteristics from a filament current of the cathode – neutralizer were observed.

In Fig. 2 the dependences of a voltage and current of the discharge from filament current are submitted when K_s = 1.45–1.55, that corresponds to the shape of a field shown in Fig. 1a. It is obvious that with growth of a filament current the discharge current is increasing because an electrons concentration is rising, and as a consequence the ionization region is expanding.

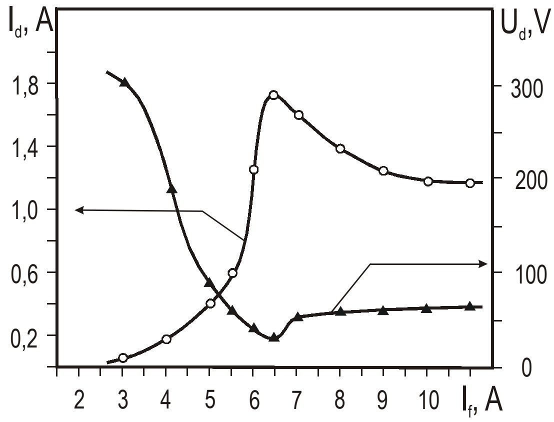


Fig. 2. Dependences of a current and voltage of the discharge from the filament current at K_s = 1.5

The presence of a maximum of the discharge current and minimum of a curve of the discharge voltage is possible to explain by existence of optimum of electronic temperature suitable for injection in a generation region of the discharge. Apparently at a filament current 6.5 A the maximum quantity of such electrons for intensification of the discharge is emitted. The subsequent reducing of a current of the discharge happens because the high energy electrons are incapable the discharge to intensity and to neutralize of a positive space charge of an ion beam [7].

The dependences are obtained in intervals K_s = 1.3–1.4; 1.6–1.9. Their typical example is shown in Fig. 3. The fields of electromagnets shapes in this case "magnetic channel" to anode layer for transporting of electrons. The curves have more complicated character with the prominent extremes. It can specify making of the requirements for an expansion of the discharge to field with major values of magnetic integral above the surfaces of the anodes [4], that gives in growth of a discharge voltage and current simultaneously. The salient maximum on a curve of a current of the discharge is evidence of a very narrow spectrum of energies of electrons, which fall into the discharge area and augment an intensity of the discharge.

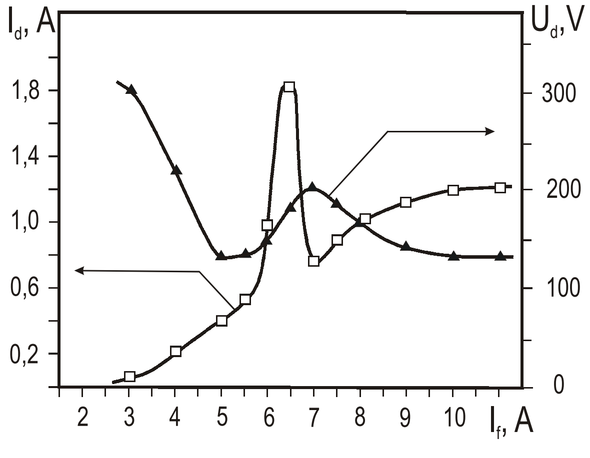


Fig. 3. Dependences of a current and voltage of the discharge from the filament current at K_s = 1.3

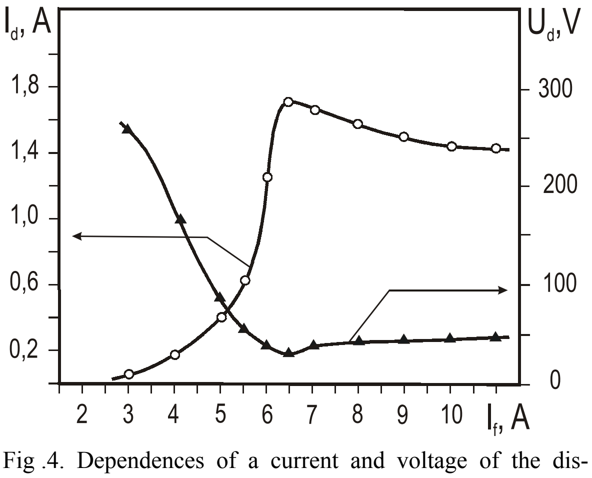


Fig .4. Dependences of a current and voltage of the discharge from the filament current at K_s = 4

The example of dependences obtained at K_s within the ranges of 0.5–1.2 and 2–4 is represented in Fig. 4. In this case a magnetic field most isotropy in the discharge area. The diagrams remind curves at K_s = 1.45–1.55 but less emphasize the extremes and show lower discharge voltage. It corroborates of the minimal value of magnetic integral in a radial direction within the accelerate channel. Such shape of a magnetic field has allowed to generate ion beams at the discharge voltage from 20 V.

It is necessary to mention, that the neutralization of an ion beam at different configurations of a magnetic field was observed already at value of a filament current more than 5 A.

Thus in the first two cases a uncompensated space charge of the beam was again observed with increase of a filament current higher 8.5 A. In the latter case the discharge remained stable.

The diagrams correspond to three mentioned above modes are submitted in Fig. 5 for qualitative comparison of the behaviors of the discharge's power from filament current at the different configurations of a magnetic field.

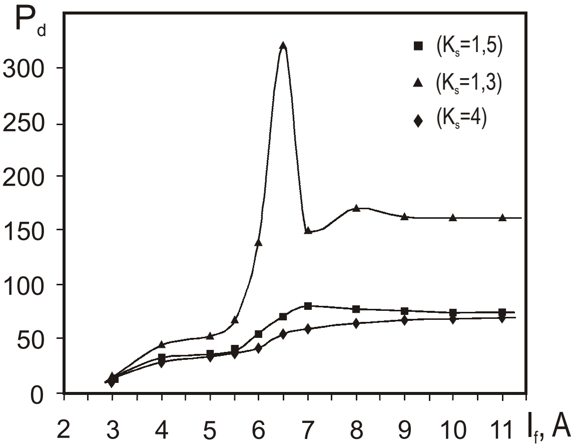


Fig. 5. Dependences power of the discharge from the filament current of the cathode at different values K_s

In the first two cases the power of the discharge are lowering at a filament current more than 8 A. In latter are increase with the subsequent saturation. It is possible to presume, that the anisotropy of a magnetic field within a discharge volume to the utmost determines narrowity of an electrons energy distribution for creating the low energy discharge in a crossed electrical and magnetic field. In the latter case a deficiency of the slow electrons, obviously, was made up owing to a great number of elementary processes of ionization, recharge and gas neutralization taking place in the all volume of the discharge area.

As is known, the increase of an emission from the filament-cathode usually leads to lowering the plasma potential and growth of an electronic temperature. The actual quantities of these values depend on the parameters of the discharge, pressures of gas in a discharge area and potential of the filament-cathode [7] and will be given in the following paper.

4. Conclusions

As a result of the carried out experimental investigations the optimal operation modes of the filament-cathode are determined at different configurations of a magnetic field in the discharge area. The features of the discharge ignition and degree of neutralization of a positive space charge of an ion beam are detected at a variation by magnitude and direction of magnetic flux lines.

The opportunities of increasing of the discharge power in crossed electrical and magnetic fields more than in 2 times was determined at shaping “magnetic channel” to region above the effective areas of anodes.

The features of the operation modes of the filament are investigated with the purpose of creation of the low voltage discharges for generating high-current, low energy (20–300 eV) broad ion beams.

Such directional ion streams will find an application in technological processes of deposition of optical thin-film layers and coats from materials with advanced density and hardness by the ion-beam assisted methods. It will allow to increase an adhesion and packing density, to form preferred orientation and to control a step of a crystalline lattice of deposited layers, to carry out low energy modification of a surface and synthesis of solid-state structures from a gas phase.

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