USING OF ELECTRON CYCLOTRON RESONANCE DISCHARGE IN ION BEAM SPUTTERING SYSTEMS FOR SPACE CHARGE COMPENSATION

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The possibility of using a magnetic mirror in the output gap of ion source with a closed electron drift to generating of an additional gas discharge by using the electron-cyclotron resonance to compensate of the ion beam space charge is studied. The first experiments have shown that an additional microwave discharge generated in the region of the annular gap when the microwave power is applied. An additional plasma source of electrons provides the maintenance and intensification of the gas discharge in the accelerator with an anode layer.

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INTRODUCTION

A common characteristic of all beam-plasma systems is the separation of ions and electrons due to the acceleration of the ionized substance. The main feature of low and medium energy (E_i < 10^4 eV) ion-beam systems, which are mainly used in vacuum-plasma technologies, is that the impact ionization of molecules and atoms of the residual gas by an ion beam in the transport region is insignificant and, as a consequence, there are no electrons that can neutralize the space charge of the ion beam. As a result, the electric fields of the space and surfaces charges created by the beam interfere with the efficient transport of ion beams under low gas pressure conditions and lead to expansion, deceleration and even beam locking in a case if the virtual emitter is formed. To neutralize these effects, electron injection into the ion beam in closed drift accelerators additional thermal cathodes located close to the output gap of cathodes-magnetic circuits are used.

A special feature of closed electron drift ion sources (ion accelerators with anodic layer (AAL) and closed electron drift ion accelerators with extended acceleration zone ACDEZ) is magnetic mirror located close to the output gap formed by the magnetically conducting source cathodes. The electromagnetic system creates the maximum magnetic field in the annular gap of the accelerator. The main difference between AAL and ACDEZ is that the maximum strength of the radial magnetic field, which is 1500…2000 Oe for AAL, and 200…500 Oe for ACDEZ.

To excite electron cyclotron resonance discharge at cathode regions of AAL and ACDEZ it is necessary to determine the operating frequencies of microwave generators. An analysis of the distribution and magnetic fields strength has shown that the industrial frequencies 2.45 GHz for AAL (resonance point at 875 Oe), and 560 MHz for ACDEZ (the resonance point at 200 Oe) can be chosen.

The topology of the magnetic field in the radial direction (in the direction of the cathodes-magnetic circuits of the magnetic system) in these sources is analogous to an open magnetic mirror.

The design and experimental work to create a plasma cathode was based on ion-beam sputtering system (IBSS), which is shown in Fig. 1.

The distribution of the magnetic field in the AAL along the distance of the discharge gap is shown in Fig. 2. In the region close to anode and the outer section of the accelerator, the radial component of the magnetic field gradually decreases.

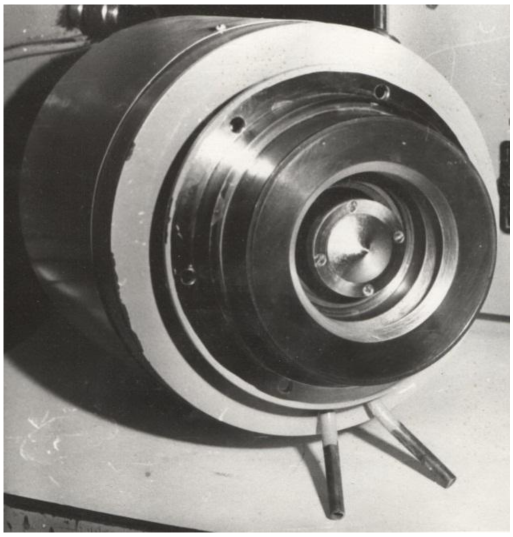

Fig. 1. Image of the ion-beam sputtering system

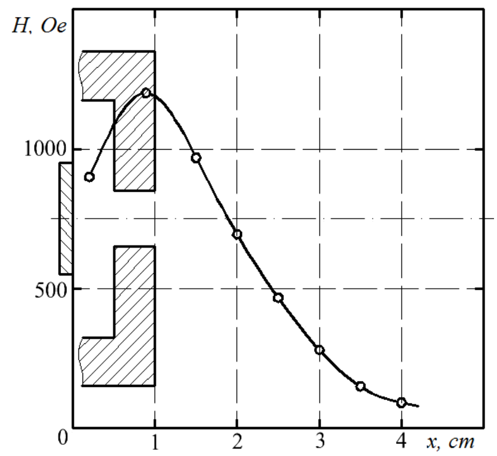

Fig. 2. Distribution of the magnetic field strength close to the discharge gap in the AAL

It is attracted attention that there is magnetic field at a considerable distance from the discharge gap, that is, in a large part of the ion beam transport space close to the accelerator cathode with a characteristic size $d_1 \leq 5$ *cm*. The shape of the spatial distribution of the magnetic field strength can be changed by changing the profile of the cathodes-magnetic circuit of the AAL [1-4].

The purpose of this work is to develop a plasma electron source that provides maintenance and intensification of the gas discharge in the AAL, as well as charge and current neutralization of the ion flux by electrons using features of the design of sources of this type.

The main idea of this project is using of a magnetic mirror at the output gap of ion sources with a closed electron drift to create an additional gas electron cyclotron resonance discharge.

EXPERIMENTAL TECHNIQUE

To check this idea, modification of ion-beam sputtering system (ILRS) based on a modified ALL during sputtering conductive and dielectric targets has been performed a schematic representation of which is shown in Fig. 3.

The main design elements of modified ion source are ring anode, cathode block and magnetic system, sputtering target fixed on movable water-cooled holder.

The industrial power supply unit BP-94 (11) served as the source of power supply for the ALL (discharge voltage of 1…6 kV) and a magnetic system (0…5 A). It is also possible to measure the current and floating potential of the substrate holder.

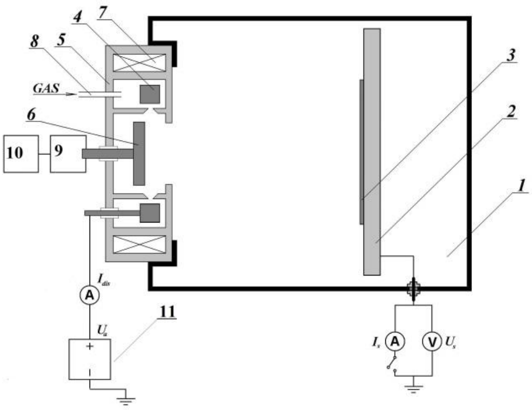

Fig. 3. Schematic diagram of the ion-beam sputtering system based on the modified accelerator with an anode layer:1 – vacuum chamber; 2 – substrate holder; 3 – sprayed sample; 4 – water-cooled annular anode; 5 – body-magnetic cathode block; 6 – water-cooled holder of the sputtered target; 7 – magnetic field solenoid; 8 – working gas supply; 9 – matching device microwave generator; 10 – microwave generator; 11 – power supply unit AAL type BP-94

The vacuum system was assembled on the basis of a series vacuum unit UVN-71P, which provided a pumping speed of up to 1500 l/s in the pressure range $p=8\cdot10^{-6}…10^{-3}$ *Torr* and the ultimate of the residual gas pressure $6\cdot10^{-6}$ *Torr*.

The ion source, due to ballistic focusing, formed a cone-shaped ion beam with a vertex from the anode plane at a distance of 50 mm. The size of the ion beam transporting space from the source to the surface of the sputtered target could be controlled by varying the target position from 15 to 30 mm, which allowed changing the annular sputtering region on the target surface.

The pressure of the working gas was regulated by a needle inflow in the range $p = 8\cdot10^{-6}…10^{-3}$ *Torr*. The working gas was introduced through the channels of the cathode block into the discharge gap of the anode-cathode.

After ignition of the discharge, when the discharge gap is filled with charged particles, the pattern of the distribution of the electric field changes and is determined not only by geometric dimensions, but also by discharge conditions: magnetic field strength, accelerating voltage, working gas pressure, etc. Under the conditions of our experiments, the Hall parameter was $\omega_{He}\tau_e >> 1$, the mobility of electrons across the magnetic field is sharply limited and a layer of negative space charge is formed at the anode, in which practically all the voltage drop in the discharge is concentrated.

Under conditions of limited mobility of electrons, the external electric field localized in the anode layer performs work mainly over ions formed in the processes of ionization of the atoms of the working substance by electron impact. The energy of singly charged is determined by the expression ε_{ib} = 0.2…0.3 eV.

To form a plasma cathode-source of electrons, it is necessary to provide conditions for the existence of a discharge at the electron cyclotron resonance in the region of the annular gap of the AAL magnetic circuit. For this, capacitance type antennas can be used, which create the maximum intensity of the microwave electric field in the region of the circular slit of the magnetic cores-cathodes of the AAL. These can be disks or rings located axially symmetric to the discharge gap of the ALL. In our experiments, a disk water-cooled holder of a sputtered target was used as microwave antenna (6).

To match the microwave generator with the antenna and plasma load, a microwave matching device was developed, designed and assembled on the basis of a transition with matching mobile pistons (Fig. 4). An operation of ion-beam sputtering system with an additional electron-cyclotron resonance discharge is shown in Fig. 5.

Fig. 4. Image of the microwave matching system

Fig. 5. Image of an additional electron-cyclotron resonance discharge in the ion-beam sputtering system

During the design, configuration and operation of the microwave system microwave generator with output power 0…150 W was used: In the working mode it is planned to use generator with an output power of 0…600 W.

CONCLUSIONS

The first experiments (physical start-up of the system) showed that an additional microwave discharge generated in the region of the annular gap when the microwave power is applied. Changing of the discharge shape glowing corresponds to a changing of the magnetic profile in the output gap when the current in the magnetic system changes. An additional plasma source of electrons provides the maintenance and intensification of the gas discharge in the accelerator with an anode layer, as well as the charge and current neutralization of the ion beam by the electrons.

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ИСПОЛЬЗОВАНИЕ ЭЛЕКТРОННО-ЦИКЛОТРОННОГО РЕЗОНАНСНОГО РАЗРЯДА ДЛЯ КОМПЕНСАЦИИ ОБЪЕМНОГО ЗАРЯДА В ИОННО-ЛУЧЕВЫХ РАСПЫЛИТЕЛЬНЫХ СИСТЕМАХ

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Изучена возможность использования ловушки пробочного типа в выходном зазоре источника ионов с замкнутым электронным дрейфом для генерации дополнительного газового разряда с использованием электронно-циклотронного резонанса и компенсации пространственного заряда ионного пучка. Первые эксперименты показали, что генерируется дополнительный СВЧ-разряд в области кольцевого зазора при подаче СВЧ-мощности. Дополнительный плазменный источник электронов обеспечивает поддержание и интенсификацию газового разряда в ускорителе с анодным слоем.

ВИКОРИСТАННЯ ЕЛЕКТРОННО-ЦИКЛОТРОННОГО РЕЗОНАНСНОГО РОЗРЯДУ ДЛЯ КОМПЕНСАЦІЇ ОБ'ЄМНОГО ЗАРЯДУ В ІОННО-ПРОМЕНЕВИХ РОЗПИЛЮВАЛЬНИХ СИСТЕМАХ

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Вивчено можливість використання пастки пробочного типу у вихідному зазорі джерела іонів із замкнутим електронним дрейфом для генерації додаткового газового розряду з використанням електронно-циклотронного резонансу та компенсації просторового заряду іонного пучка. Перші експерименти показали, що генерується додатковий НВЧ-розряд в області кільцевого зазору при подачі НВЧ-потужності. Додаткове плазмове джерело електронів забезпечує підтримку та інтенсифікацію газового розряду в прискорювачі з анодним шаром.