SOLID ION ACCELERATOR BASED ON MAGNETRON SPUTTERING DISCHARGE

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A new solid ion accelerator based on magnetron sputtering discharge is described. The ions of working gas are used to bombard and sputter a cylindrical target made of metal or dielectric material. The sputtered atoms can be ionized and extracted by an ion optical accelerating system. Tests have shown that the ion source can operate stably for a long time that is principally defined by the target consumption. The mixed beam consisting of various solid ions (*B*, *C*, *Si*, *Ti*, *V*, *Fe*, *Ni*, *Ta*, *W*) and ions of working gas can be obtained.

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1. INTRODUCTION

The sources of ions of solid materials are used for implantation of impurities and dopants, thin-film deposition, material modification. Designs of metal ion sources can be divided into several types depending on the boiling-point and ionization potential of required metals. If metal has low boiling temperature than metal vapor can be obtained by moderate metal heating and can be feed into the ion source having more or less typical design [1,2]. Ions of metals, which have a relatively low ionization potential, can be obtained due to surface ionization directly on the hot metal surface [3,4]. But these methods applied for metals with a high melting temperature provide only a little beam current. In this case a vacuum arc ion source is convenient [5]. In this source a metal vapor vacuum arc discharge is used for plasma production. In this type of the ion source the pulse duration reaches 100 *μs*, pulse reiteration frequency is about 1 pulse per second and beam current is about 10 *mA*.

Ions of different metals may be also obtained by sputtering from an electrode in a discharge. It is clearly that only sputtered-based sources have simple construction and can operate under room temperature. Owing to configuration of the electrical and magnetic fields being orthogonal, stable glow discharges and intense sputtering of cathode material can be obtained in a magnetron at low pressures.

In this paper the design and performance of the solid ion source based on the hollow-cylindrical magnetron sputtering discharge is described.

2. DESIGN

The sketch of the accelerator is presented in Fig.1. It consists of an ion source with ion-optical accelerating system and focusing lens. The basic elements of the construction of the hollow-cylindrical magnetron sputtering ion source are the following: anode (1), cathode block (2) and magnetic system (3).

The water-cooled end anode is made of non-magnetic stainless steel and is electrically isolated from the cathode block. The anode is powered and cooled through the isolated vacuum feedthroughs in the bottom of the cathode block.

The water-cooled cathode block of the ion source is multi-functional. It is used as a housing of the ion source, as a magnetic circuit, and as a cathode of the discharge gap. The magnetic system, gas inlet and extraction electrode are installed in the cathode block. The cathode block consists of the water-cooled hollow-cylindrical housing with end flanges made of magnetically soft material (4) which also is used as a holder of sputtered target (5). The target is fixed in the cathode block by hold-down nut (6) and by electrode-extractor (7).

The magnetic system (3) consists of a hoop with permanent magnets which is fixed on the cathode block housing and magnetically soft end flanges of the cathode block. The magnetic system produces the arch magnetic field with a peak intensity of 500 Oe near the interior surface of the sputtered target.

The working gas pressure is adjusted in a range of $10^{-2}...10^{-3}$ Torr. The working gas is fed through the channels of the cathode block (8) into the cathode-anode discharge gap.

The cathode can be capacitively coupled to a 13.56 MHz RF power supply with a power up to 2.5 kW or can be connected to the DC power supply with a negative potential up to 1000 V with respect to the anode. The electric field crossed with magnetic field and applied to the sputtered cathode (5) creates intense plasma in the near cathode region. From this region argon ions are extracted and accelerated by the cathode potential and sputter the target surface mainly in the region of the magnetic field arch. The parameters of the discharge in the DC mode are the following: voltage of 500 V and current up to 5 A. The density of the sputtered atoms grows beginning at the cathode surface towards the cathode axis. The electrons move also from the discharge region across the magnetic field towards the system axis where the electron current density is maximal and the total current of electrons is a discharge one. Thus, in this discharge configuration, both the density of the sputtered atoms and density of electrons peak at the system axis. This provides effective ionization of sputtered target atoms. The extraction of ions is performed by the electrode-extractor (7).

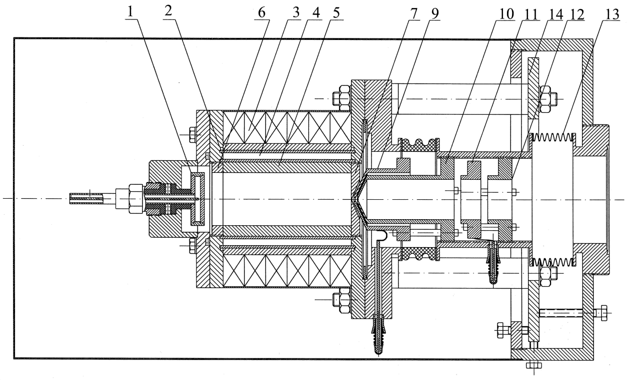

Fig.1. The sketch of the ion source with the ion-optical accelerating system and focusing lens. 1- anode, 2- cathode block, 3- magnetic system, 4- water-cooled hollow-cylindrical housing with end flanges, 5 - sputtered target, 6 - hold-down nut, 7 - and electrode-extractor, 8 - gas inlet pipe, 9 - focusing electrode, 10 - accelerating electrode, 11, 12 – electrodes of electrode electrostatic formative lens, 13 - vacuum bellows joint, 14 - mechanical driver

The advantage of such a construction of the ion source is fairly small losses of sputtered material owing to isolation of the gas discharge volume. The non-extracted atoms are deposited on the target surface and can be sputtered again. This fact, coupled with the absence of hot cathodes in the source construction, provides a greatly enlarged operational life of the target and opportunity to operate with chemically active working substances.

The ion optical accelerating system produces electric field which extracts ions from the magnetron discharge plasma and forms them into a beam. The electrode shape of the acceleration system approaches to Pierce geometry. It consists of electrode-extractor (7) installed into the cathode block, focusing electrode (9) and accelerating electrode (10). The use of three-electrode ion optical accelerating system is required for spatial stabilisation of the emissive plasma boundary at different accelerating voltage in a wide range from 0.5 to 10 kV.

Three-electrode lens (10, 11, 12) with the internal diameter of 30 mm is used for additional ion beam focusing. The lens insulators are shielded from the beam to prevent charging and spark track formation. Three-electrode lens shape and focus the ion beam in a drift space to the position of a diaphragm. The inner diameter of the diaphragm is 3 mm. The lens with a large diameter provides high-quality ion optical properties of the beam with minimum spherical aberration.

3. THE ION SOURCE OPERATION

During experiments the discharge voltage (U_{dis}), discharge current (I_{dis}) and pressure (p) were measured.

The discharge was initiated in the area of the sputtered target, under such conditions: voltage was in the range of U_{dis}=325…530 *V* and discharge current changed in the range of I_{dis}=0.3…8 *A*, pressure was in the range of $p= 5\cdot10^{-4}…5\cdot10^{-3}$ *Torr*. Fig.2 shows typical voltage-current plots at different pressures.

The electron current density distribution along the radius of the hollow-cylindrical sputtered cathode at different discharge parameters was also measured (Fig.3). It can be seen that the electron current reaches a value of discharge current at the system axis, i.e. the stream of electrons from the discharge region travels across a magnetic field in radial direction towards the system axis. The stream of sputtered atoms is formed and travels also towards the cathode axis where the sputtered atom density peaks. Thus, in the given discharge configuration, both the density of sputtered atoms and the density of electrons have the peak at the system axis. This provides the effective ionization of sputtered target atoms and the enhanced current of extracted solid ions.

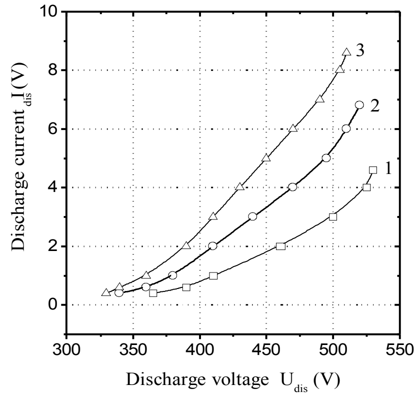

Fig.2. Voltage-current plots under different pressures: 1 – p=3·10⁻⁴ Torr, 2 – p=8·10⁻⁴ Torr, 3 – p=3·10⁻³ Torr

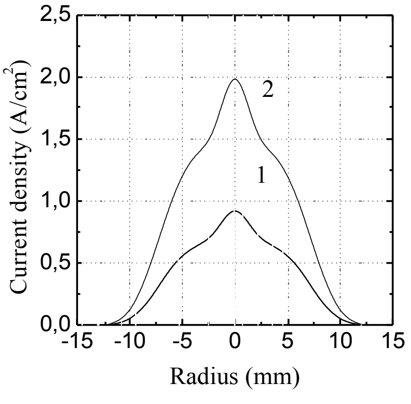

Fig.3. The current density distribution along the beam radius: 1 – I_{dis}=5 A, 2 – I_{dis}=8 A. p=3·10⁻³ Torr

4. CONCLUDING REMARKS

A new solid ion source is described. The ion source based on the hollow-cylindrical magnetron sputtering discharge produces the beam of various solid ions (*B*, *C*, *Si*, *Ti*, *V*, *Fe*, *Ni*, *Ta*, *W*) which are then extracted by an ion optical accelerating system. In this ion source DC discharge is used for generation of the ions of different metals and the capacitively coupled RF discharge with a frequency 13.56 *MHz* is used for generation of ions of other solid materials.

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УСКОРИТЕЛЬ ТВЕРДОТЕЛЬНЫХ ИОНОВ НА БАЗЕ МАГНЕТРОННОГО РАСПЫЛИТЕЛЬНОГО РАЗРЯДА

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Представлен новый ускоритель твердотельных ионов на базе магнетронного распылительного разряда. В таком ионном источнике ионы рабочего газа используются для бомбардировки и распыления цилиндрической мишени, сделанной из металла или диэлектрического материала. Распыленные атомы могут быть ионизированы и извлечены ионно-оптической ускоряющей системой. Испытания показали, что ионный источник может устойчиво работать в течение длительного времени, которое преимущественно определяется расходом мишени. Получены смешанные ионные пучки, состоящие из различных твердотельных ионов (*B*, *C*, *Si*, *Ti*, *V*, *Fe*, *Ni*, *Ta*, *W*) и ионов рабочего газа.

ПРИСКОРЮВАЧ ТВЕРДОТІЛЬНИХ ІОНІВ НА БАЗІ МАГНЕТРОННОГО РОЗПИЛЮЮЧОГО РОЗРЯДУ

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Представлено новий прискорювач твердотільних іонів на базі магнетронного розпилюючого розряду. В такому іонному джерелі іони робочого газу використовуються для бомбардування і розпилювання матеріалів, які використовуються як циліндрична мішень. Розпилені атоми іонізуються й екстрагуються іонно-оптичною прискорюючою системою. Випробування показали, що іонний прискорювач може стабільно працювати протягом довгого часу без аніяких проблем і потребує лише заміни розпилюваної мішені. Отримані пучки різноманітних твердотільних іонів (*B*, *C*, *Si*, *Ti*, *V*, *Fe*, *Ni*, *Ta*, *W*) змішаних з іонами робочого газу.