ON A POSSIBILITY OF CREATION OF POSITIVE SPACE CHARGE CLOUD IN A SYSTEM WITH MAGNETIC INSULATION OF ELECTRONS

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We describe a new approach for creation an effective, low-cost, low-maintenance axially symmetric plasma optical tools for focusing and manipulating high-current beams of negatively charged particles, electrons and negative ions. This approach is based on fundamental plasma optical concept of magnetic insulation of electrons and non-magnetized positive ions providing creation of controlled uncompensated cloud of the space charge. The axially symmetric electrostatic plasma optical lens is well-known and well developed tool where this concept is used successfully. This provides control and focusing high-current positive ion beams in wide range of parameters. Here for the first time we present optimistic experimental results describing the application of an idea of magnetic insulation of electrons for generation of the stable cloud of positive space charge by focusing onto axis the converging stream of heavy ions produced by circular accelerator with closed electron drift. The estimations of a maximal concentration of uncompensated cloud of positive ions are also made.

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1. INTRODUCTION

It is known that the problem of manipulating intense beams of charged particles retains its actuality already for many years. An idea of the space charge use for that purpose [1] expressed for the first time by Gabor at the beginning of the past century appeared to be very favorable. Plasma-optical principles of introducing spatial epithermal E-fields in the plasma medium of intense ion beam proposed a bit later by A.I. Morozov on a basis of idea of magnetic isolation of electrons resulted in essential progress in the problems of focusing and manipulating of high-current beams of positive ions including those of heavy ions possessing current values in a range of amperes [2]. Progress in creation of the new materials enables the present development and construction of electrostatic plasma lenses with predetermined focusing features on a basis of permanent magnets.

Recent achievements in a creation of negative ion sources raise a problem of development of focusing devices capable of manipulating intense negative ion beams. Proposed for the first time plasma lens with positive space charge is based on the idea of electrostatic isolation of electrons [3].

Unlike that case, in the present work the possibility of use of the devices with magnetic isolation of electrons for creation of dynamic cloud of positive space charge is studied experimentally. The work presents the results of preliminary researches of potential distribution in non-compensated ion flow which converges onto axis of symmetry of the system. Presence of the potential maximum at the center of such system, and dependence of formation of the potential distribution on a pressure in the chamber and accelerating potential at the system anode are demonstrated.

2. EXPERIMENTAL SETUP

In the present work toroidal plasma accelerator with anode layer (ALA) was used as a device with magnetic isolation of electrons for creation of dynamic cloud of positive space charge. Beam of positively charged argon ions formed by the device converged in the system center whereas electrons were magnetized in the anode layer. Schematic diagram of experimental setup is shown in Fig.1.

ALA was placed in vacuum chamber. Cathode of the source was grounded, and DC voltage in a range of 0…2000 V was supplied from power source to the anode. System of permanent magnets 3 formed the field ~ 0,05 T in the interelectrode gap. Argon with working pressure range of $3\times10^{-5}\dots3\times10^{-3}$ Torr was used as plasma generating medium. For measurement of floating potential, Langmuire probe (5) and electrostatic volt- and kilovoltmeter of C50 type were used. The system of the probe mount allowed it positioning in any point at the plane parallel to the system axis and passing through it. Langmuire probe was assembled in a common way with sensitive part having 347 μm diameter and 4,5 mm length.

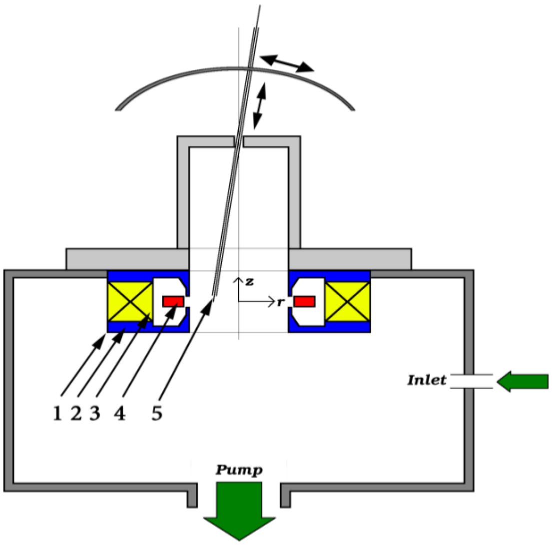

Fig.1. Schematic diagram of the setup.
1 – ALA, 2 – cathode, 3 – magnetic system,
4 – anode, 5 – Langmuire probe

3. EXPERIMENTAL RESULTS

Measurements of floating potential at the system axis performed for different operating parameters of the source enabled determination of optimum conditions for accomplishing of the experiments: the pressure of order of 5×10^{-5} Torr and the voltage of 1 kV. Typical distributions of floating potential along Z and R axis at different parameters of the system are presented in Figs. 2-3.

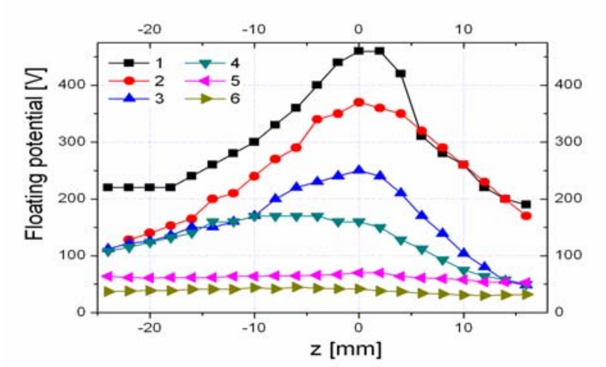

Fig.2. Floating potential at Z axis for supply voltage Ud=1 kV, r=0 at different pressure values: 1 – 3×10^{-5} Torr; 2 – 5×10^{-5} Torr; 3 – 7×10^{-5} Torr; 4 – 1×10^{-4} Torr; 5 – 2×10^{-4} Torr; 6 – 4×10^{-4} Torr

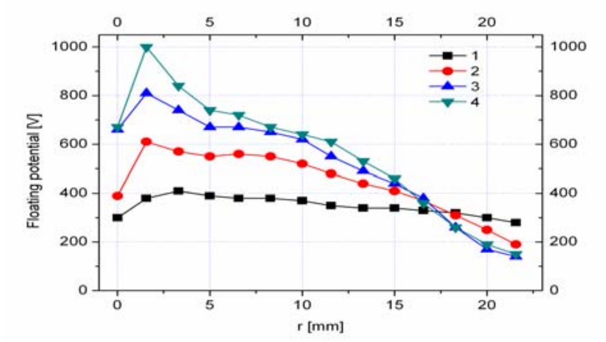

Fig.3. Floating potential at z = 0, p = 5×10^{-5} Torr for different discharge voltage values: 1 – 500 V; 2 – 1000 V; 3 – 1500 V; 4 – 2000 V

Map of spatial distribution of floating potential is shown in Fig.4 One can see that the potential distribution has complex shape. Maximum of the potential occurs in cylindrical region coaxial with the system axis rather than at that axis.

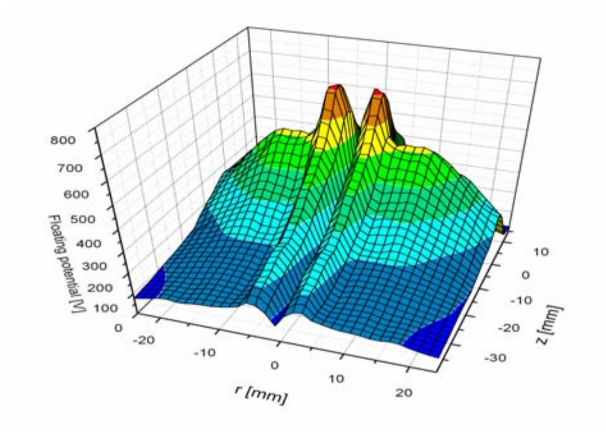

Fig.4. Floating potential distribution in the system (p = 5×10^{-5} Torr, Ud = 1000 V)

Results of the measurements of ion current onto the probe in the system center are shown in Fig.5. One can see that the current obeys the rule of ballistic focusing $I(r) \sim 1/r$ excluding region of the system center.

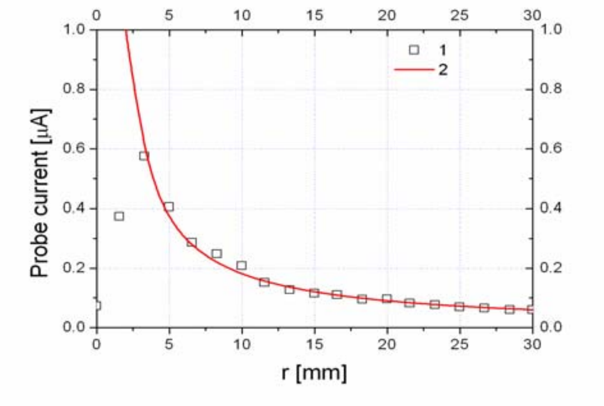

Fig.5. Ion current in radial plane (z = 0, p = 5×10^{-5} Torr, Ud = 1000 V): 1 – experiment; 2 – estimation curve Id = 1,8/r (μA)

4. THEORETICAL ESTIMATIONS

An estimation of equilibrium ion concentration n_i in the space charge cloud formed by the ion flow converging to the axis is possible if one would assume that the ions come into cylindrical volume separated at the system axis due to the beam from ALA channel, and leave along Z axis due to action of electric field of their own space charge. Then the equality is valid

$$j_i 2\pi r h = \frac{e n_i}{\tau_i}\pi r^2 h,$$

where j_i is beam current density at the boundary of current-collecting surface with radius r and height h, and τ_I is mean time of ion residence in the cloud

$$n_i = \frac{2 j_i \tau_i}{e r}.$$

Ion residence time in a region with typical dimension $r>>h$ can be estimated if one knows velocity of this ion. With simplifying assumption of the uniform distribution of ions in the cylinder, ions slip down from parabolic hump of the potential having a fall of $d\varphi$. Then their mean energy equals 1/3 $d\varphi$.

From equation for the potential, neglecting r coordinate, we obtain

$$\Delta\varphi \cong \frac{\partial^2\varphi}{\partial z^2} = -4\pi e n_i,$$

$$\langle d\varphi\rangle = \frac{d\varphi}{3} = \pi e n_i h^2/6,$$

$$v_i = \sqrt{2\frac{e}{M}\langle d\varphi\rangle} = eh\sqrt{\frac{\pi n_i}{3M}},$$

$$\tau_i = \frac{h/2}{v_i} = \frac{1}{2e\sqrt{\frac{\pi n_i}{3M}}}.$$

Taking $d\varphi = 400 - 500V$ we can derive:

$$n_i^{3/2} = \frac{j_i}{re^2}\sqrt{\frac{3M}{\pi}};\ n_i = 5\cdot 10^{10}\ cm^{-3}.$$

5. CONCLUSIONS

Accomplished researches have shown principal possibility of the use of cylindrical accelerator with anode layer, which forms positive ion flow converging onto the axis, for creation of positive charge cloud. It enables possibility of development of plasma lens with essentially undercompensated positive space charge, which will be useful for focusing and manipulating the beams of negatively charged particles.

Dimensions of positive charge cloud formed at the axis, and steady state of the cloud depending on plasma-dynamics parameters of the system are determined experimentally.

It is defined by the experiment that ion flow dynamics at radial axis of the device follows the rule of ballistic focusing.

Electric field value, which can reach 600 V/cm, realized under experimental conditions of such system is determined. Such electric field strength is sufficient for creation of short-focus focusing elements to be used in the systems for producing intense beams of negatively charged particles, negative ions and electrons.

ACKNOWLEDGEMENT

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О ВОЗМОЖНОСТИ СОЗДАНИЯ ОБЛАКА ПОЛОЖИТЕЛЬНОГО ПРОСТРАНСТВЕННОГО ЗАРЯДА В СИСТЕМЕ С МАГНИТНОЙ ИЗОЛЯЦИЕЙ ЭЛЕКТРОНОВ

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Описан новый подход к созданию эффективных, недорогих аксиально-симметричных плазмо-оптических приборов для фокусировки и управления сильноточными пучками отрицательно заряженных частиц: электронов и отрицательных ионов. Этот подход основан на фундаментальной плазмооптической идее использования магнитной изоляции электронов и незамагниченности ионов для создания контролируемого нескомпенсированного электронного облака пространственного заряда. Примером широко распространенного и детально разработанного устройства, где описанная идея успешно используется, может быть аксиально-симметричная электростатическая плазменная линза. Она позволяет контролировать и фокусировать сильноточный положительный пучок ионов в широком диапазоне параметров. В работе впервые представлены оптимистичные экспериментальные результаты, описывающие применение идеи магнитной изоляции электронов для создания стабильного облака положительного пространственного заряда путем фокусировки на ось сходящегося потока тяжелых ионов, поставляемых тороидальным ускорителем с замкнутым дрейфом электронов. Сделаны оценки максимальной концентрации ионов в облаке нескомпенсированного положительного заряда.

О МОЖЛИВОСТІ СТВОРЕННЯ ХМАРИ ПОЗИТИВНОГО ПРОСТОРОВОГО ЗАРЯДУ В СИСТЕМІ З МАГНІТНОЮ ІЗОЛЯЦІЄЮ ЕЛЕКТРОНІВ

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Запропоновано новий підхід до створення ефективних, недорогих аксіально-симетричних плазмово-оптичних приладів для фокусування та керування сильнострумовими пучками негативно заряджених часток: електронів та негативних іонів. Цей підхід базується на фундаментальній плазмооптичній ідеї щодо використання магнітної ізоляції електронів та незамагниченності іонів у створенні керованої нескомпенсованої електронної хмари просторового заряду. Прикладом широко вживаного та добре розвинутого приладу, де зазначена ідея успішно використовується, може бути аксиально-симетрична електростатична плазмова лінза. Вона дозволяє контролювати та фокусувати сильнострумові позитивні пучки іонів в широкому діапазоні параметрів. В роботі наведено оптимістичні експериментальні результати, що описують застосування ідеї магнітної ізоляції електронів для створення стабільної хмари позитивного просторового заряду шляхом фокусування на вісь потоку важких іонів, які генеруються тороїдальним прискорювачем з замкненим дрейфом електронів. Зроблено оцінки максимальної концентрації іонів в хмарі нескомпенсованого позитивного заряду.