THE DEVELOPMENT OF THE POSITIVE SPACE CHARGE PLASMA LENS FOR MANIPULATING HIGH CURRENT BEAMS OF NEGATIVELY CHARGED PARTICLES

***A.N. Dobrovolskiy*[1], *S.P. Dunets*[1], *A.N. Evsyukov*[1], *A.A. Goncharov*[1], *V.I. Gushenets*[2], *I.V. Litovko*[3], *E.M. Oks*[2]**

[1]Institute of Physics NAS of Ukraine, Kiev, Ukraine;
[2]High Current Electronics Institute SD RAS, Tomsk, Russia;
[3]Institute for Nuclear Research NAS of Ukraine, Kiev, Ukraine
E-mail: gonchar@iop.kiev.ua

We describe the development of the plasma lens with dynamic positive space charge for manipulating and focusing intense beams of negative charge particles. Floating potential spatial distributions in lens with modified magnetic field are investigated. It is shown that magnitude of magnetic field at the lens cloud area doesn't impact essentially on floating potential distributions. Interrelation between the value of floating potential maximum and anode potential value is demonstrated experimentally. With anode potential growing the efficiency of space charge creation decreases and the electric field magnitude depends weakly upon anode potential at given pressure in the lens.

PACS: 52.40.Mj

1. INTRODUCTION

The manipulation of negative charged particle beams is the actual problem in basic science and modern technologies. Use of the basic plasmaoptics idea [1] for these applications led to the significant progress in this field [2]. Since series of effective plasma lens modifications for positive ion beams focusing was produced and tested, an axially symmetric electrostatic plasma lens is a well-explored tool for manipulating and focusing intense large-area moderate-energy positive heavy ion beams [3].

As it was shown earlier a plasma lens with a positive space charge can be a very attractive and efficient device for focusing of intense negatively charged particle beams [4,5]. It is possible to create the space charge using both electrostatic electron insulation and magnetic electron insulation. But in the last case it is possible to reach a stronger focusing electric field (up to 600 V/cm against 100 V/cm). Such electric field strength is sufficient for creation of short-focus elements to be used in systems for manipulating intense beams of negative ions and electrons. Here we present the new results of investigations of the plasma lens that uses magnetic electron insulation for creation of a positive space charge.

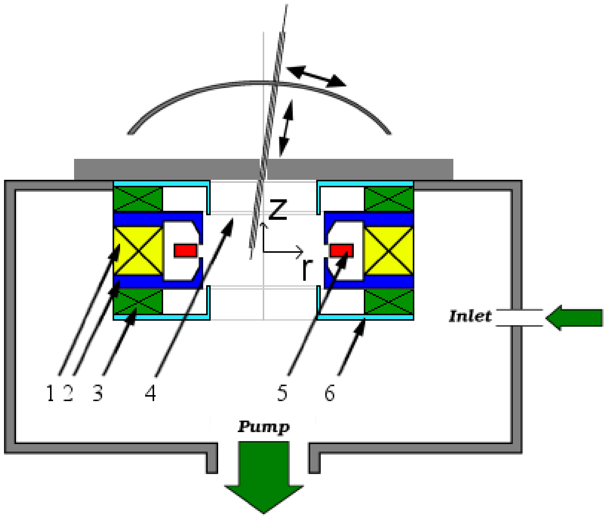

Fig. 1. Experimental set-up: 1 – magnetic system; 2 – cathode; 3 – additional magnetic system; 4 – Langmuir probe; 5 – anode; 6 – additional pole pieces

2. EXPERIMENTAL RESULTS

The plasma lens described in [5] was modified to restrict the influence of the finite magnetic field in the lens volume on the particles dynamics. We have mounted additional magnetic system to decrease the magnetic field near the lens axis. The scheme of experimental set-up is shown on Fig. 1. In our measurements we use Langmuir probe with a cylindrical current-collective surface of 0.37 mm in diameter and 5.5 mm in length.

We measured floating potential distributions in the plasma lens volume using electrostatic voltmeter (Fig. 2). The new magnetic field (white solid lines) does not change the floating potential distribution in the modified lens in comparison with the previous lens modification [6]. The floating potential maximum is located not at the axis exactly. This can be explained by the ions transversal pulse acquired in the strong magnetic field of discharge channel[7].

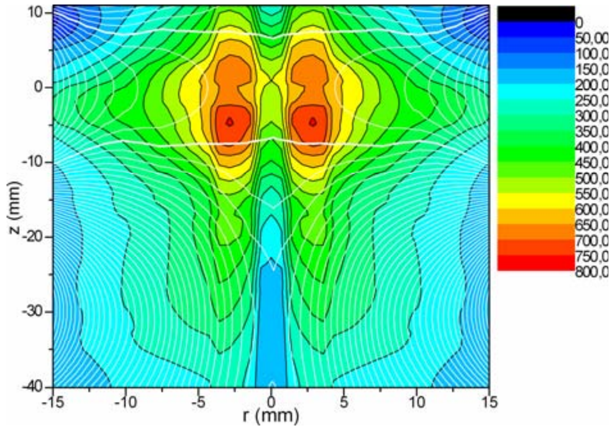

Fig. 2. Floating potential distribution in the plasma lens volume at pressure 5×10^{-5} Torr, discharge voltage 1500 V (white solid lines are magnetic field lines, black ones – electric equipotential lines)

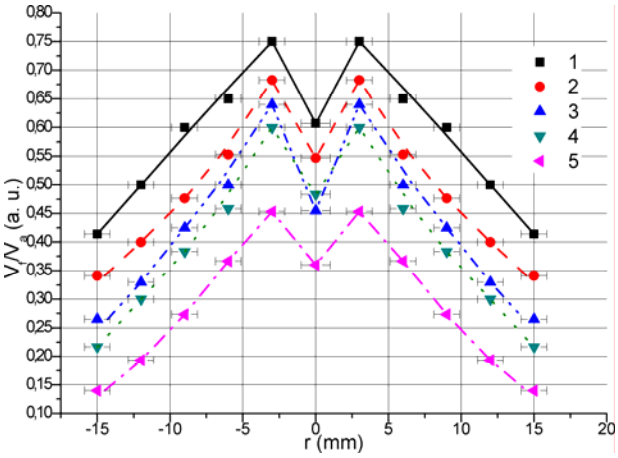

Fig. 3. Floating potential profiles normalized to corresponding anode potential at pressure 5×10^{-5} Torr, z = 0, discharge voltage: 1 – 700 V; 2 – 850 V; 3 –1000 V; 4 – 1200 V; 5 – 1500 V

Floating potential profiles normalized to the anode potential are shown on Fig. 3. With discharge voltage growing, the efficiency of the anode potential transfer to the space charge potential decreases. At the same time the average radial electric field and the maximum floating potential demonstrate quasi-linear dependencies on the discharge voltage (Fig. 4). We suppose the electric field is strong enough to create a short focus plasma lens for negatively charged particles.

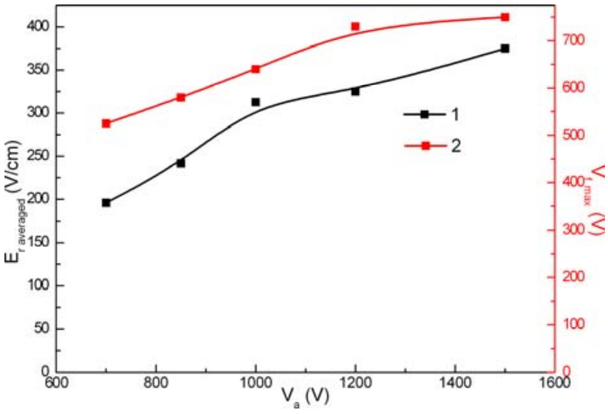

Fig. 4. Average radial electric field (1) and maximum floating potential (2) in the plasma lens volume vs. anode potential at pressure 5×10^{-5} Torr

We also investigated dynamic characteristics of this plasma lens. It was established that the space charge cloud is not stationary in time. Typical oscilloscope traces of the current in cloud area on grounded probe and discharge current are shown on Fig. 5; here the probe position corresponds to the maximum floating potential on Fig. 2. The probe current amplitude has a maximum along radius; the maximum position coincides with the position of the floating potential maximum. Discharge current also demonstrates the periodical signal. With pressure growing the frequency of the saw-tooth probe current oscillations increases linearly as shown on Fig. 6.

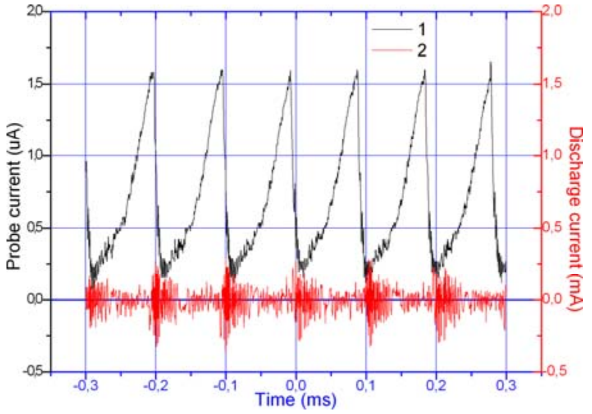

Fig. 5. Typical probe current (1) and discharge current (2) oscilloscope traces at pressure 5×10^{-5} Torr, r = 3 mm, z = 0, and discharge voltage 1200 V

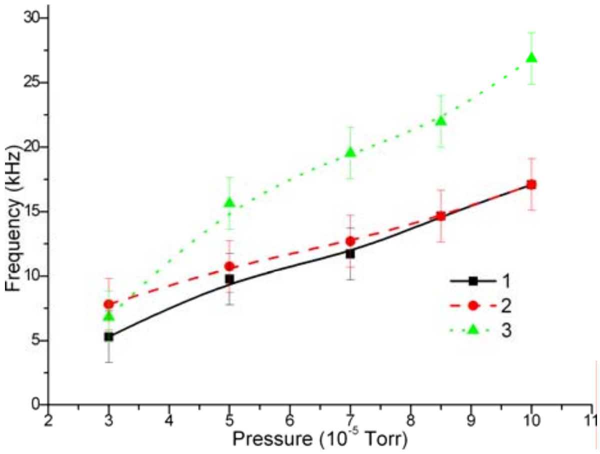

Fig. 6. Frequency of saw-tooth probe current oscillations vs. pressure for different anode potentials (r = 3 mm, z = 0): 1 – 1000 V; 2 – 1200 V; 3 – 1500 V

We have extended our theoretical model [5] taking into account the ion angular and energy distributions. We assume that ions angular distribution has a form $N(\Theta)/N(0)\approx\cos(\Theta)$, where $N(\Theta)$ is an amount of ions that move at an angle Θ; Θ is in (r, z) plane. Besides we took into account the magnetic field in the lens. Without going into details we can note that the results of the PIC-simulations are in a qualitative accordance with experimental data.

3. CONCLUSIONS

Thus, in the paper some static and dynamic characteristics of positive space charge plasma lens with magnetic insulation of electrons are described. It is shown that strong electric field, up to 500 V/cm suitable for focusing high-current negative ion and electron beams are achieved. It is shown that decreasing of magnetic field at the lens cloud area doesn't impact essentially on floating potential distributions. With anode potential growing the performance of space charge creation decreases and the electric field magnitude depends weakly upon anode potential at given pressure in the lens. Noted oscillations is inherent for systems of such kind and usually connected with generation and escape of charged particles.

ACKNOWLEDGEMENTS

The work was supported in part by the Russian Foundation for Basic Research and State Foundation for Basic Research of Ukraine under the program of joint Russian-Ukrainian research projects (RFBR Grant No 09-08-90409 and SFBRU Grant No F28/264-2009).

REFERENCES

1. A. Morozov, S. Lebedev. “Plasmaoptics” // *Reviews of Plasma Physics*/ Edited by M.Leontovich. New York: “Consultants Bureau”, 1975.
2. A. Goncharov, A. Dobrovolsky, A. Zatuagan, I. Protsenko. High-current plasma lens // *IEEE Trans. Plasma Sci.* 1993, v. 21, N 5, p. 573.
3. A.A. Goncharov, I.G Brown. High-current heavy ion beams in the electrostatic plasma lens// *IEEE Trans. Plasma Sci.* 2004, v. 32, N 1, p. 80-83.
4. V.P. Goretskii, I.A. Soloshenko and A.I. Shchedrin. Space charge lens for focusing negative-ion beams // *Plasma Physics Reports*. 2001, v. 27, N 4, p. 335-339.
5. A.A. Goncharov, A.M. Dobrovol’skii, S.P. Dunets, A.N. Evsyukov, I.M. Protsenko. On a possibility of creation of positive space charge in a system with magnetic insulation of electrons // *Problems of Atomic Science and Technology. Series "Plasma Physics" (15).* 2009, N 1, p. 150-152.
6. A. Dobrovolskiy, S. Dunets, A. Evsyukov, A. Goncharov, V. Gushenets, I. Litovko, E. Oks. Recent advances in plasma devices based on plasma lens configuration for manipulating high-current heavy ion beams // *Rev. Sci. Instrum.* 2010, v. 81, p. 02B704.
7. A.A. Bizyukov, A.I. Girka, K.N. Sereda, A.V. Nazarov, E.V. Romaschenko. Hall Ion Source with Ballistic and Magnetic Beam Focusing // *Problems of Atomic Science and Technology. Series “Plasma Physics” (14).* 2008, N 6, p. 174-176.

Article received 07.10.10

УСОВЕРШЕНСТВОВАНИЕ ПЛАЗМЕННОЙ ЛИНЗЫ С ПОЛОЖИТЕЛЬНЫМ ПРОСТРАНСТВЕННЫМ ЗАРЯДОМ ДЛЯ УПРАВЛЕНИЯ СИЛЬНОТОЧНЫМИ ПУЧКАМИ ОТРИЦАТЕЛЬНО ЗАРЯЖЕННЫХ ЧАСТИЦ

А.Н. Добровольский, С.П. Дунец, А.Н. Евсюков, А.А. Гончаров, В.И. Гушенец, И.В. Литовко, Е.М. Окс

Представлены результаты дальнейшего развития плазменной линзы с динамическим положительным пространственным зарядом для управления сильноточными пучками отрицательно заряженных частиц. Исследовано пространственное распределение плавающего потенциала в линзе с измененным магнитным полем. Показано, что уменьшение магнитного поля в области накопления заряда не оказывает существенного влияния на распределение потенциала в объеме. Экспериментально продемонстрирована взаимосвязь величины максимума плавающего потенциала с анодным потенциалом в системе. Эффективность трансформации анодного потенциала в фокусирующий потенциал линзы падает с ростом первого в пределах измеренных давлений в объеме линзы.

ВДОСКОНАЛЕННЯ ПЛАЗМОВОЇ ЛІНЗИ З ПОЗИТИВНИМ ПРОСТОРОВИМ ЗАРЯДОМ ДЛЯ КЕРУВАННЯ СИЛЬНОСТРУМОВИМИ ПУЧКАМИ НЕГАТИВНО ЗАРЯДЖЕНИХ ЧАСТОК

А.М. Добровольський, С.П. Дунець, А.М. Євсюков, О.А. Гончаров, В.І. Гушенець, І.В. Литовко, Є.М. Окс

Представлено вдосконалення плазмової лінзи з динамічним позитивним просторовим зарядом задля керування сильнострумовими пучками негативно заряджених часток. Досліджено просторовий розподіл плаваючого потенціалу в лінзі зі зміненим магнітним полем. Показано, що зменшення магнітного поля в області накопичення заряду не справляє суттєвого впливу на розподіл потенціалу в об'ємі. Експериментально продемонстровано взаємозв'язок між значенням максимуму плаваючого потенціалу та анодним потенціалом в системі. Ефективність трансформації анодного потенціалу у фокусуючий потенціал лінзи падає зі зростанням першого в досліджених межах тиску в об'ємі лінзи.