MODEL OF SPACE CHARGE PLASMA LENS FOR FOCUSING NEGATIVE CHARGED PARTICLE BEAMS

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Introduction

Recently [1, 2] we proposed and investigated a new original plasma-optical tool for negative charged particle beams focusing and manipulating with a dynamic cloud of non-magnetized free positive ions and magnetically isolated electrons produced by a toroidal plasma source like an anode layer thruster. In such kind systems the electrons are separated from ions by relatively strong magnetic field in the discharge channel. The accelerated ions are weakly affected by the magnetic field owing to their mass and accumulated in the cylinder volume until their own space charge creates a critical electric field. The positive space charge cloud produced by this way allows operating without complicated traps for positive ions and dynamic manipulating lens properties. In our preliminary works [3, 4] we described model and have been investigated processes of positive space charge cloud accumulation. There was shown that focusing electric fields up to 400 V/cm could be reached and possibilities of the controlled electrostatic focusing of the intense negative charge particle beams.

Here we describe the new experimental and simulation results of wide-aperture (6 cm) non-relativistic (up to 18 keV) intense (up to 400 mA) electron beam focusing by the positive-space-charge plasma lens. Focusing of the electron beam by electrostatic plasma lens was separated from magnetic focusing experimentally and the compression factor was up to 5.

Experimental and computer simulation results

The plasma electron source based on electron extraction from vacuum arc discharge with hollow anode was used for generation of the beam. The circular plasma accelerator with anode layer (ALA) was used as a device with magnetic insulation of electrons for creation of the dynamic cloud of positive space charge. A detailed description and some preliminary results of the operation of the setup have been described previously [1, 2]. Then the combined effect of electrostatic and magnetic lens was obtained that created difficulties for separating electrostatic and magnetic focusing. The preliminary experiments allow to clear construction flaws of the setup and taking them into account for improvement and modernization.

The lens was optimizes on some parameters. At first – decreasing magnetic field value in channel allows reducing its impact on the ion's trajectories and restricted their momentum aberrations as well as to lower magnetic field influence on electron beam focusing. However, it has no significant effect on the operation of the discharge, forming convergent ion beam on the axis. At second – changing the construction of the anode lens allowed to increase the maximum potential of the anode is almost twice. This led to an increase the optical strength of the lens and reduced ion's spin in transverse magnetic field of the accelerator. Due to these modifications the electrostatic focus location of electron beam was separated from magnetic and arrangement before it. The results of experimental measurement are shown on Fig 1.

The electron beam current density distribution on the axis after plasma lens passing is shown on the left side. Ones can see that plasma lens operation (curve 3) lead to focus distance decreasing and additional beam compression in comparison with only magnetic lens action (curve 2). The beam current density at the focus increase up to 5 time as compared with lens off and almost twice in case beam focusing by magnetic field only. The focus distance is 150 mm for electron beam energy 10 keV passing through plasma lens with anode potential 2.4 keV with according to experimental measurements. The electron beam current density radius distribution in electrostatic cross-section is shown on Fig. 1 right. If lens off and magnetic field is absent (curve 1) – beam is spatially homogeneous. Magnetic lens action leads to beam compression (curve 2), the switching on electrostatic plasma lens leads to noticeable additional beam compression (curve 3). Thus the intensive wide-aperture electron beam focusing by positive space charge electrostatic lens with electron magnetic isolation was firstly demonstrated experimentally.

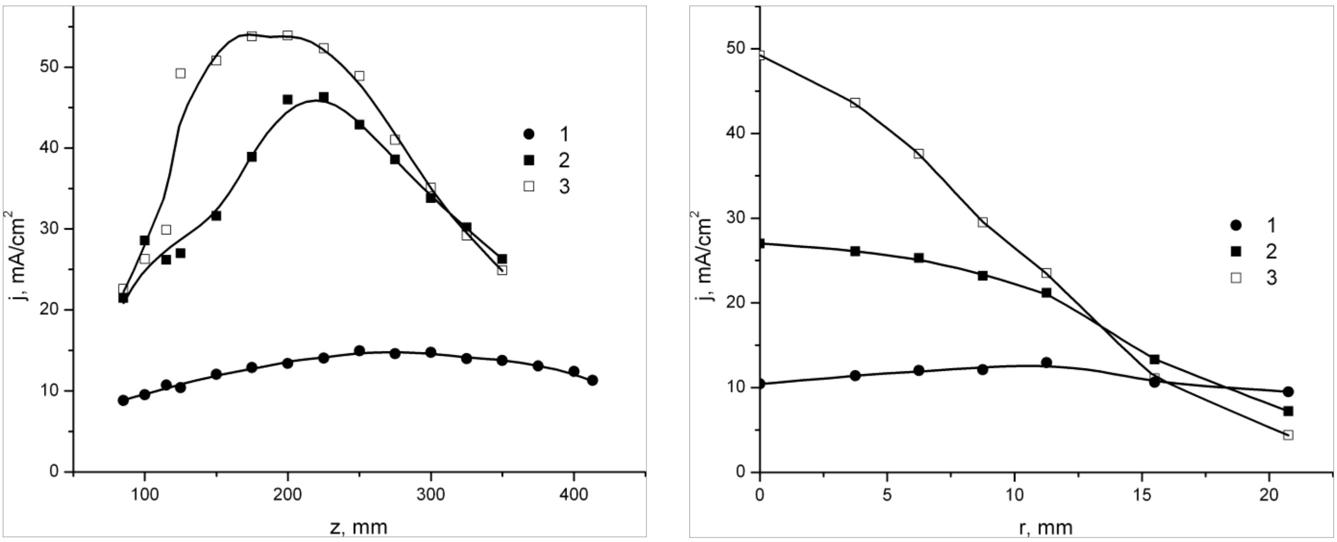

Fig 1. The electron beam current density distribution. Left – on the axis; Right – at the electrostatic lens focus cross-section. 1 – Lens off and magnetic field absent; 2 – magnetic lens (the anode potential is zero); 3- plasma lens with the same magnetic field.

For computer simulation we used the model described before in our previous papers [3, 4] the conditions of the numerical experiment are similar to the experimental. Results are shown on Fig. 2 and Fig. 3. On Fig 2 are shown trajectories of electron beam passing through lens with positive space charge cloud and magnetic field (up) and through magnetic lens only (down). One can see that space charge cloud lead to additional visible beam compression and moving focus closer to lens. If focus distance for magnetic lens was about 28 cm and beam radius 22mm, than switching lens on leads to shift focus distance to 15 cm and beam radius reducing up to 14 mm. The electron beam current density distribution is shown on Fig. 3. Left - distribution along beam propagation direction; right – in electrostatic focus location cross-section (15cm). Thus it is seen that the switch on the positive space charge electrostatic lens leads to improvement of electron beam focusing. The simulation results confirmed experimental data and there are in a good agreement with them. It should be noted that in case of negative ion beam focusing effect of the magnetic field on the beam is much less because of the large difference in masses of electrons and ions. The effectiveness of the electrostatic focusing of the mass of the particles does not depend, therefore, a beam of negative ions should focusing by plasma lens as effective as the electron beam [5], although beam compression ratio could be vary due to the peculiarities of electron and negative ion beams generation, formation and propagation.

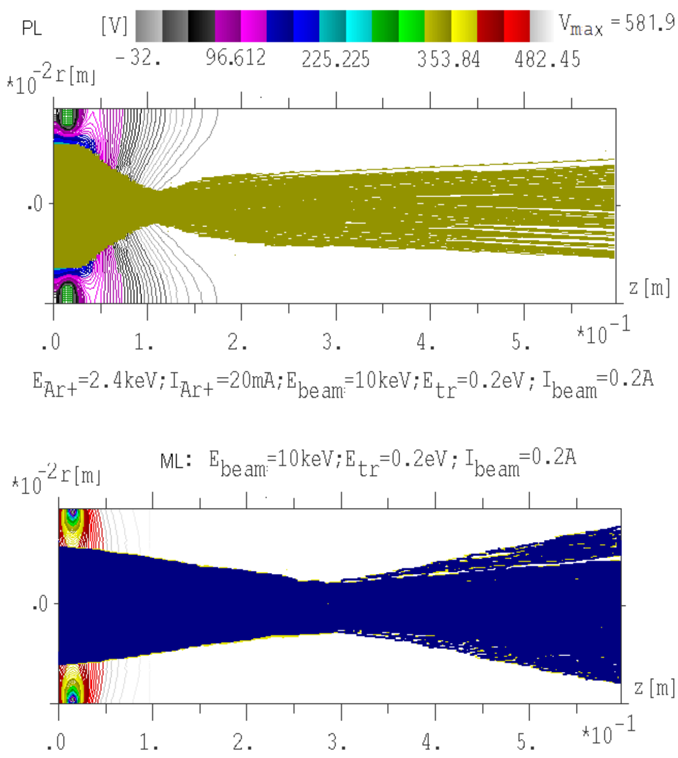

Fig 2. The electron beam current trajectories: up – electrostatic positive space charge lens with magnetic field; down – magnetic lens only. Beam parameters: I=0,2A, E=10keV. U_a = 2.4kV, I_{Ar}=20mA

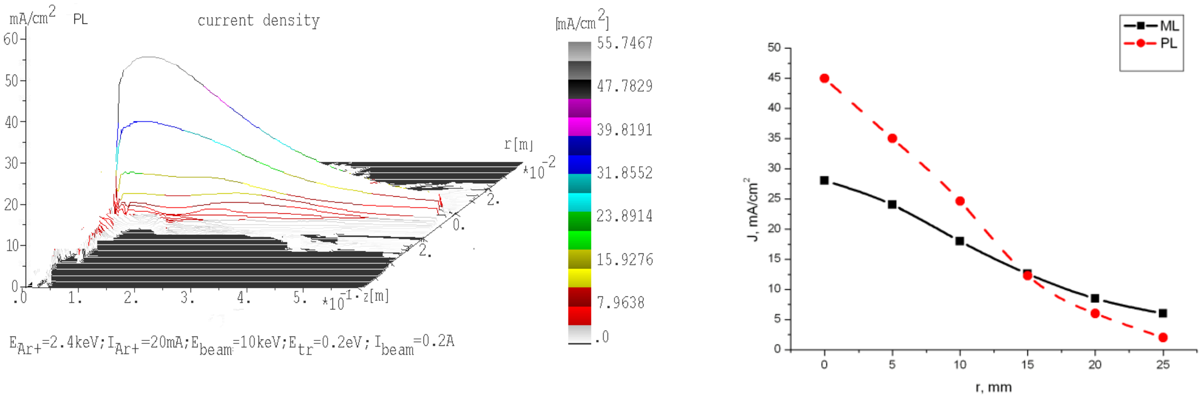

Fig 3. The electron beam current density distribution. Left – along the axis; Right – at the electrostatic lens focus cross-section (red –electrostatic lens with magnetic field; black – magnetic lens only)

Conclusion

A model for positive space charge electrostatic lens with electron magnetic isolation was developed and applied for focusing by negatively charged particles beam. The intensive wide-aperture electron beam focusing by positive space charge electrostatic lens with electron magnetic isolation was firstly demonstrated experimentally. The calculations results are in a good agreement with experimental.

The proposed plasma lens is essentially a thin transparent sheet of plasma for the transmitted and focused beam of negative ions. Estimates show that in these circumstances should not be a significant loss of beam due to recharging. This allows us to talk about the prospects of using electrostatic plasma lenses for focusing and controlling by intense beams of negatively charged particles, electrons and negative ions. Obtained experimental results demonstrate the possibility to create a low-cost high-effective tool for negatively-charged particle beam focusing without influence of momentum aberrations.

References

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