COMPUTER MODELLING OF THE NEGATIVE CHARGED PARTICLE BEAMS FOCUSING BY POSITIVE SPACE CHARGE PLASMA LENS

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Introduction

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 have been proposed and studied recently[1]. 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. Creation by this way positive space charge cloud allows to control the positive ions dynamic and lens properties without any essential predicaments. The experimental and simulation research results submitted in preliminary works [2-4] had shown an attractive possibilities of perspective application dynamical positive space charged plasma lens with magnetic electron insulation for focusing and manipulating wide-aperture high-current no relativistic electron beams. Here we describe further elaboration of the numerical model based on the PIC-method for positive space charge plasma lens and negatively charged particle beams (electron and ions) passing through the lens. It is found plasmodynamical conditions for stable operation of the space charge plasma lens. This paper describes development numerical model and new computer simulation results of a wide-aperture non-relativistic electron beam that transported through an axially symmetric device with a positive space charge plasma lens.

Simulation model and results

The calculation were performed by means of the “particle in cell” method [5]. At first the positive space charge cloud formation was modeling. Under simulations we take into account dynamic of Ar+ ions only, because of magnetic insulation of electrons. Every time interval Δt ($\sim 4\cdot 10^{-8}$ sec) N new particles of charge q_i and mass M_i come to the considered volume. The magnitudes of N, Δt, q_i satisfy the relation: $Nq_i/\Delta t = j_i S$. They move from cylinder surface to the system axis with the angular distribution according to cosine law: $N(\Theta)/N(0) \approx \cos(\Theta)$, where N(Θ) are quantities of ions going out under angle Θ, N(0) is angular distribution amplitude. It should be noted that the distributions above are inherent to this kind of plasma accelerators with anode layer. The particles move in magnetic field that decreases drastically towards to system axe. At first step, the motion equation for the particles in space charge fields was solved (time step comprised 10^{-11} s). After the time of Δt, by coordinating of all particles with the use of the ‘‘cloud in cell’’ method [5] the distributions of densities of argon ions were calculated. Electric field was calculated by the distribution of total space charge. After that in corrected electric field the motion of particles was resumed, and introducing the new portion of ions was performed. Equation of motion was solved both for “new” particles and for those that still left in the volume. The calculation continued until reaching a self-consistent solution. Time in the calculations comprised 10^{-5}s. For that time the stationary state was achieved of the lens operation. The calculated potential distribution in cloud has one-humped form and reached 580 V in maximum [1,2]. The calculated electric field strength was up to 600V/cm that is sufficiently for focusing intensive negative charged particle beams. After that the transport large-area (r=3 cm) electron beam with energy from 5 to 20 keV and current from 0.1A to 100 A through this dynamical cloud was investigated. For simulation high-current electron beam transport was taking into account the space charge of the particles and the magnetic self-field that may influence the beam particles themselves in addition to the external fields. The possibility ionization residual gas by electron beam was taking into account also. From numerical simulations evidently that for electron beam current of 1 A, the maximum potential in the positive space charge region decreases (from 580V to 210V) , it distribution is getting double-humped and electrostatic focusing destroyed (see Fig.1).

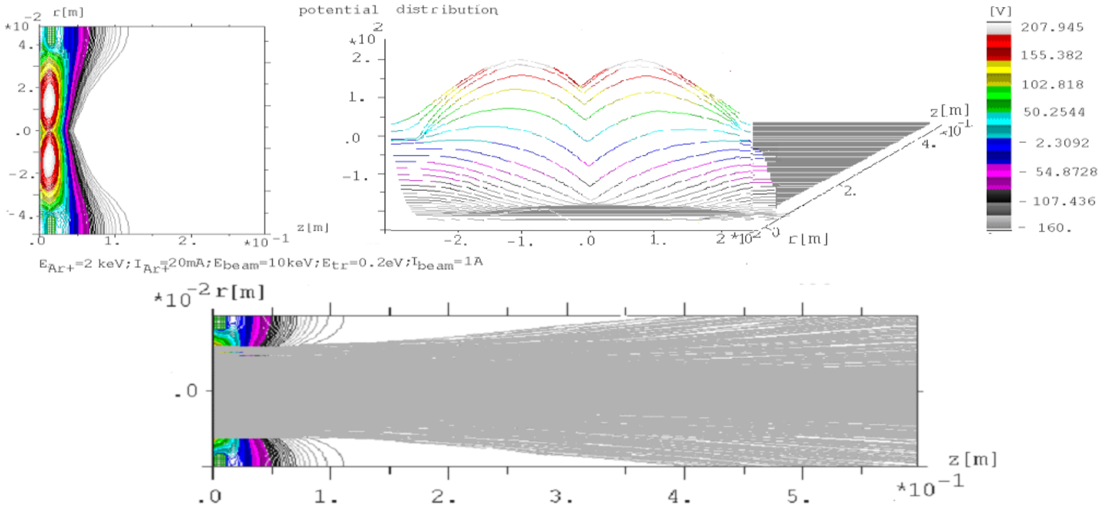

Fig.1: Potential distribution in PL (top) and electron beam trajectories (down) under electron beam (energy(E_{eb})=10keV, current(I_{eb})=1A) passing through PL. Ar+-ions beam energy (E_{ib})=2.4 keV, current (I_{ib})=20 mA, magnetic field (MF) ~50 Oe on the axis.

It is connected to that some part of ions comes out from cloud with the electron beam. Significant part of cloud particles carry out by e-beam along beam line and the quantities of trapped ions are increase with increasing electron beam current (see Fig. 2). Ions that continuing to come in cloud from electrodes couldn't support renewal processes. Thus cloud potential decrease and it distribution changes from one-hump to two-humps.

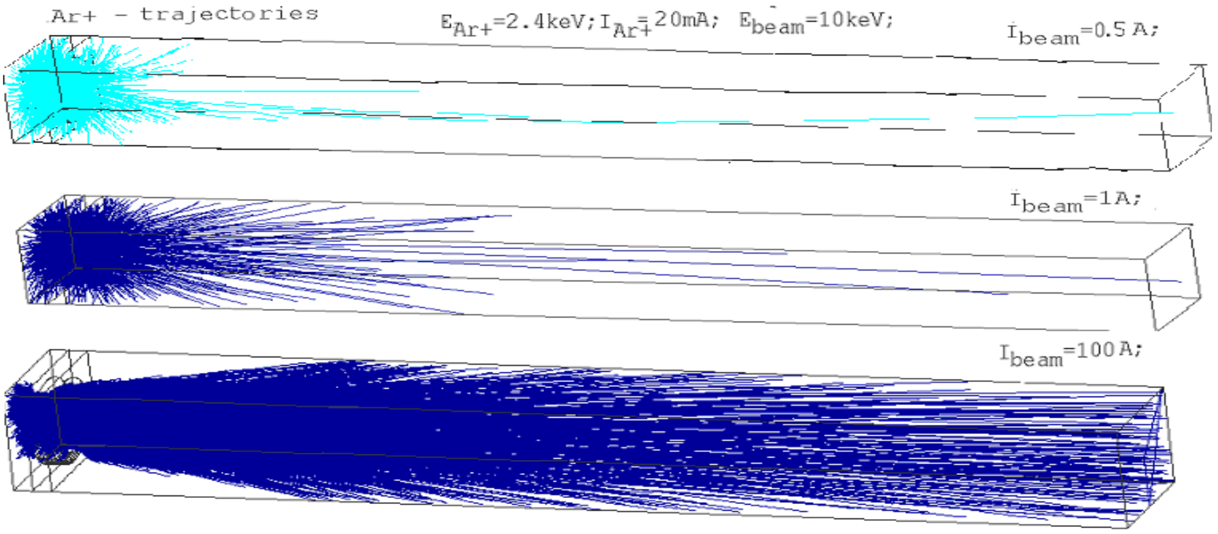

Fig.2: Trajectories of Ar+-ions under electron beam passing through PL. Ar+-ions: E_{ib}*=2.4 keV,* I_{ib}*=20 mA. Electron beam:* E_{eb}*=10 keV,* I_{eb}*=0.5A (top), 1A (middle), 100 A(down)*

Note that in case when beam space charge density a bit exceeds to space charge cloud density (I_{eb} ~1A) is possible to improve PL electrostatic focusing property by increasing energy and current density Ar+ ions beam that positive space charge cloud create. In Fig. 3 is shown potential distribution under electron beam passing for increasing Ar+ ions beam current from 20 mA to 40 mA. Ones can see potential distribution come back to one-peak form and focusing properties PL has been recovered.

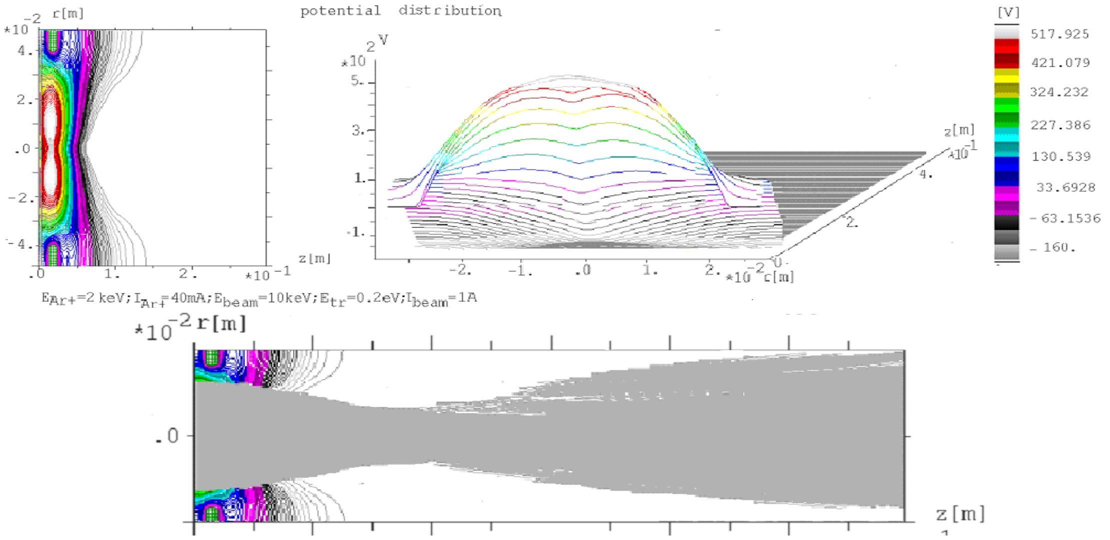

Fig.3: Potential distribution in PL (top) and electron beam trajectories (down) under electron beam (E_{eb}*=10 keV,* I_{eb}*=1A) passing through PL.* Ar^+*-beam:* E_{ib}*=2.4 keV,* I_{ib}*=40 mA; MF ~50 Oe*

However with further electron beam current increasing when beam space charge density significantly exceeds space charge cloud density (for I_{eb}>10A), the cloud quickly destroys(see Fig.4) and PL focusing properties has been lost. It is not possible to renew electrostatic focusing properties any more and survive magnetic focusing only. Thus the plasma lens will operates in the quasi neutral plasma mode and provides plasma density required for the accelerating, formation and stable transport of the high-current pulsed electron beam.

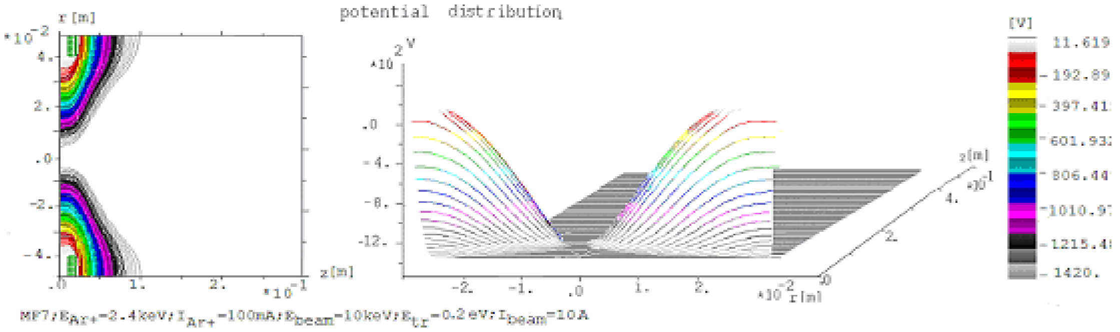

Fig.4: Potential distribution in PL under electron beam (E_{eb}=10 keV, I_{eb}=100A) passing through PL. Ar+-ions E_{ib}=2.4 keV, I_{ib}=20 mA.

Conclusion

The submitted simulation results demonstrate an attractive possibilities of perspective application dynamical positive space charged plasma lens with magnetic electron insulation for focusing and manipulating wide-aperture high-current no relativistic electron beams. It was shown that plasma lens significantly improve of electron beam focusing in low-current mode. In case of high-current mode while as electron beam space charge much more than space charge plasma lens the lens operates in plasma mode to create transparent plasma accelerating electrode and producing additional plasma density required for the formation and stable transport of the intensive electron beam.

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