

HIGH-CURRENT ION BEAMS IN THE ELECTROSTATIC PLASMA LENS

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1. Introduction

Investigations of electrostatic plasma lenses were started in works [1,2]. Experiments, carried out in 70-th for relatively low-current ion beams (1-100 mA), proved key statements of the theory [2], which is based on the principle of magnetic insulation of electrons and equipotentialization of magnetic strength lines. These experiments were characterized by essential exceeding of control lens potential ϕ_l over the non-compensated self potential of the ion beam ϕ_b , and as a rule, were carried out for gas ion beams. The new stage in investigations have started with a use of plasma lenses for focusing of moderate energy ampere scale gas ion beams [3]. The main distinctive peculiarity of these experiments was the fact, that they were carried out for conditions when $\phi_l \leq \phi_b$. Results of these experiments demonstrated viability of the main plasma-optical idea and ability of the plasma lens (PL) to operate effectively such beams. At the same time there were started investigations of a role of spherical aberrations in focusing and formation of the radial profile of such beams [4]. It was shown that in the high-current PL one can vary radial profile of the control potential, eliminate spherical aberrations and use them for creation of required beam profile on the target, in particular, to transform non-homogeneous ion beam profile into the homogeneous one [5]. Such universality of the PL control properties makes them an attractive tool for scientific and technological high-current set-ups operating heavy ion beams. Below we present results of investigations of focusing of wide-aperture ($\varnothing \sim 6$ cm) low and moderate energy heavy metal ion beams with total current up to 800 mA.

2. Experimental set-up and methods of measurement

Experiments were carried out on the set-up shown schematically in [6] for two modifications of the MEVVA-type ion source [7]. The source was constructed from two-chamber anode and three-electrode multi-aperture accel-decel ion-optical system (IOS). For the case of a 100-400 eV beam it was used an IOS optimized for extraction of such beams and first anode with axial aperture $\varnothing 1$ cm. For extraction of 4-25 keV beams it was used another IOS and first

anode in the form of a grid. The ion source provide creation of a low-divergent beam of heavy ions with a duration $\sim 100 \mu s$, energy up to 25 keV and current up to 800 mA. For control of beam and plasma parameters, averaged for the time 25 μs , there were used radially and axially movable Langmuir probes and axially movable sectioned collector. The source was at the distance about 30 cm from the middle plane of the lens. The diameter of the input aperture of the PL $2R=7$ cm, length $L=12$ cm, number of fixing electrodes is 9. The highest potential applied to the central electrode is up to +4 kV. Electrodes, symmetric relative to it, are connected by pairs and to the intermediate points of the divider. The lens pulse magnetic field is $H_0 \sim 0,1$ T. The residual pressure of a gas in the chamber was on the level 7×10^{-6} Torr. This provides plasma formation in the PL and drift channel by only secondary electrons of ion-electron emission.

3. Experimental results and discussion

The investigations carried out demonstrated a high efficiency of the PL effect on the heavy ion beams.

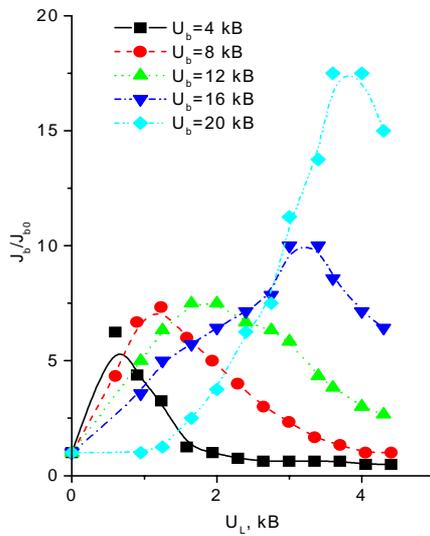


Fig. 1.

In the Fig.1 it is presented a compression coefficient for current density on the beam axis depending on applied to the lens voltage ϕ_L on the fixed distance Z from the middle plane of the PL. One can see that focusing is observed for all energies of a beam, compression increases essentially with a growth of U_b . Dependency of U_b on U_L , which provides focusing of the beam, agrees with the formula for the lens focusing distance [8].

It was shown early in the experiments with hydrogen ion beam [3], that radial profile of the static potential ($\phi_{st}(r,z)$) in the lens depends on the geometry of the magnetic field, distribution of external potential on electrodes, their number and ion beam current. In the present experiments we use optimum geometry of the magnetic field found in [3]. The character of dependency of $\phi_{st}(r)$ was varied by changing of external potential distribution on electrodes. As a result, it was found optimum distribution ($\phi_{cr}(r) \sim r^2$), which has no spherical aberrations and for which it was measured focusing characteristics of the PL.

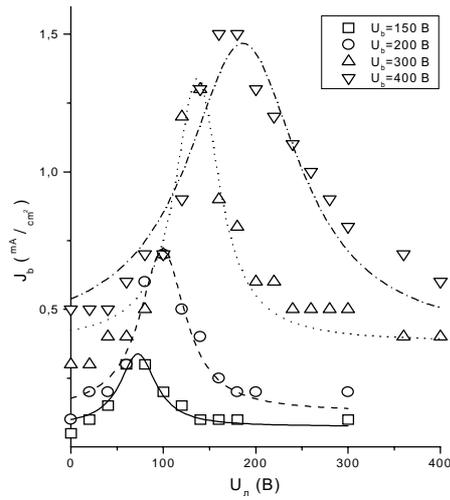


Fig. 2.

less than 1 cm. Maximum current density of the focused beam increases with a growth of the total current and achieves 160 mA/cm² for the current 800 mA.

Experiments carried out for low energy beams of different elements under conditions of optimum geometry of the magnetic field and in the absence of spherical aberrations reveal typical stepped radial profile of the current density in the focus of a beam. Data obtained for zinc and copper are shown on the Fig. 4(a,b). Width of the steps obtained increases with a growth of the PL magnetic field. Experiments, carried out for carbon ion beams in the same conditions, testify to the fact that there are no steps in the radial profile. This is in agreement with data [9].

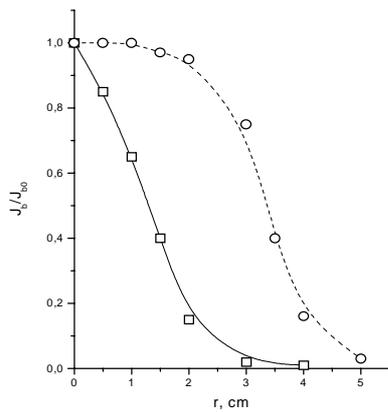


Fig. 3.

current density. Maximum compression of the parallel beam in the absence of spherical aberrations can be restricted by finite phase volume, non-compensated space charge and momentum aberrations. Calculation of the effect of these factors for conditions of

Experiments with low energy beams shown that for this case it is observed intense beams focusing by the PL. Typical dependencies of the current density on the axis on φ_1 for the fixed Z are shown in the Fig. 2. Compression of the beam current density obtained in these experiments is up to 10. Stable focusing can be achieved for magnetic fields 6×10^{-3} T. The radial profile of the moderate energy beam current density is shown in the Fig. 3. Under focusing halfwidth of the beam decreases by the factor about 3. For the low current beam (up to 80 mA) it is possible to focus practically whole beam into the spot with a diameter

An analysis of ions, passing through the PL, shows that at the exit they have not only radial V_R but also azimuthal $V_\theta = V_R V_b H_0 L / \varphi_b \pi c$ component of velocity, connected with the finite azimuthal swirl in the magnetic field. Existence of the V_θ leads to momentum aberrations. This restricts minimum radius of the spot in the focus $R_{\min} = R(V_b H_0 L / \varphi_b \pi c)$, $V_b = \sqrt{2 n e \varphi_b / M}$, where n is a multiplicity of ions charge. This leads to dependency of the size of focus spot on the charge multiplicity and enables to explain non-homogeneous structure of the profile of beam

experiments, under suggestion that ion temperature in the source is 1-3 V, by formulas from [4,8] shows that current density in the focus can be increased by the factor of 2-3 orders. The real observed beam compression in the focus is ~ 10-20. Perhaps, such discrepancy is related

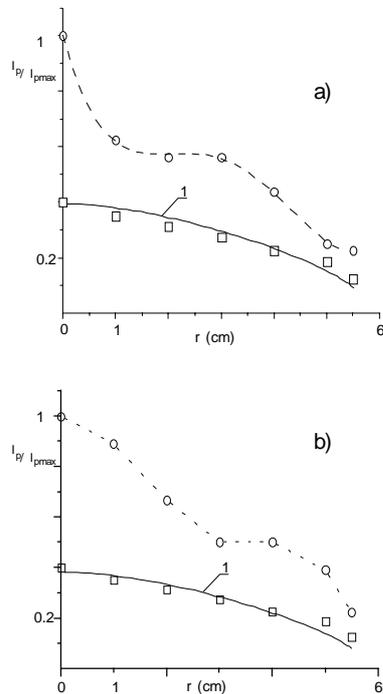


Fig. 4.

to sharp growth of the effective ion temperature in the IOS, fine structure of the radial profile of the static potential and collective effects in the volume of the PL. Note, that for hydrogen ion beams with comparable moderate energies the observed low compression (2-5) [4] may be explained taking into account electric field of the non-compensated space charge of the beam in the focus and momentum aberrations.

4. Conclusion

Thus, the obtained experimental results show the high efficiency of use of the high-current PL for focusing and control of intense heavy ion beams. This may be applied in high dose ion implantation facility and for input of the ion beam in the beamline of high current accelerators.

Acknowledgments

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References

- [1] Gabor D.: Nature **160**, 89, 1947
- [2] Morozov A.I.: Dokl. Akad. Nauk of USSR **163**, 1363, 1965
- [3] Goncharov A.A., Dobrovolsky A.N., Zatuagan A.V., Protsenko I.M.: IEEE Trans. on Plasma Sci. **21**(5), 573, 1993
- [4] Goncharov A.A., Zatuagan A.V., Protsenko I.M.: IEEE Trans. on Plasma Sci. **21**(5), 578, 1993
- [5] Goncharov A.A., Zadorojniy V.F., Dobrovolsky A.N.: JTF **67**(8), 97, 1997
- [6] Goncharov A.A., Protsenko I.M., Dobrovolsky A.N.: Rev. Sci. Instr. **67**, 1073, 1996
- [7] Brown I.: Rev. Sci. Instr. **65**, 3061, 1994
- [8] Goncharov A.A., Dobrovolsky A.N., Litovko I.V., Protsenko I.M., Zadorojniy V.F.: Rev. Sci. Instr. **67**, 1155, 1996
- [9] Brown I.: Nuclear Instr. And Methods in Physics Research B **37/38**, 68, 1989