4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Observation of nonlinear demagnification in plasma-based ion beam optics

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In conventional optics, the magnification of a lens depends upon the lens material and the geometry of the lens. The magnification is a constant for optical lenses as well as for electrostatic lenses for a set of fixed potentials applied to the electrodes. In an earlier work[1], it is reported that the demagnification factor (*DM*) of an Einzel lens system employed to focus ion beams extracted from a plasma-based ion source, varies nonlinearly when the object size (beam source size) is reduced to below the plasma Debye length (λ_d). The results indicate that the reason for nonlinearity results from the non-uniform penetration of electric fields in the plasma sheath region through the plasma electrode (PLE) aperture, from where the beams are extracted. There are no systematic studies on the effect of plasma parameters on the *DM* factor of plasma-based electrostatic focusing devices. This study for the first time shows that the effect of plasma-parameters can dictate the *DM*, in plasma-based ion beam focusing systems.

A multi-element focused ion beams (MEFIB) system[2] developed in our laboratory, consists of four major parts: plasma column, beam column, experimental chamber and stage manipulator. In the plasma column, an electron cyclotron resonance plasma is produced using microwaves of 2.45 GHz and confined in an octupole magnetic multicusp[2,3]. A compact electrostatic lens system is employed in the beam column to extract the ions from plasma and focus the beam with required energy (~ 30 KeV).

In order to calculate λ_d at various operating pressures, the electron temperature (T_e) and density (n_e) in steady state plasma are calculated numerically by solving the growth equation for T_e and particle balance equation[4] in cylindrical geometry of the multicusp. The numerical results show excellent agreement with experimental ones, measured by Langmuir probes. It is found that λ_d has a minimum value (~55 μm) at an optimum pressure ~ 0.4 mTorr, where the plasma density is maximum (~1.3× 10^{17} m^{-3}).

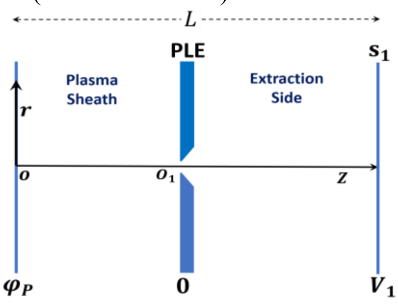

Fig. 1. Region of interest of the numerical calculation. φ_p and V_1 are the plasma potential and applied voltage to the first electrode of first Einzel lens, respectively.

To obtain the potential (*V*) and fields near plasma electrode (PLE) aperture (Fig. 1, with a magnified view in Fig 2(a)), the Poisson's equation is solved using successive over relaxation method. The variation of *V* along the axis (z), axial (E_z) electric fields for 100 μm PLE aperture is shown in Fig. 2(b). It is observed that E_z has a maximum value near the PLE aperture which is responsible for the extraction of ions from plasma. The axial electric field near the PLE aperture depends upon the size of the aperture.

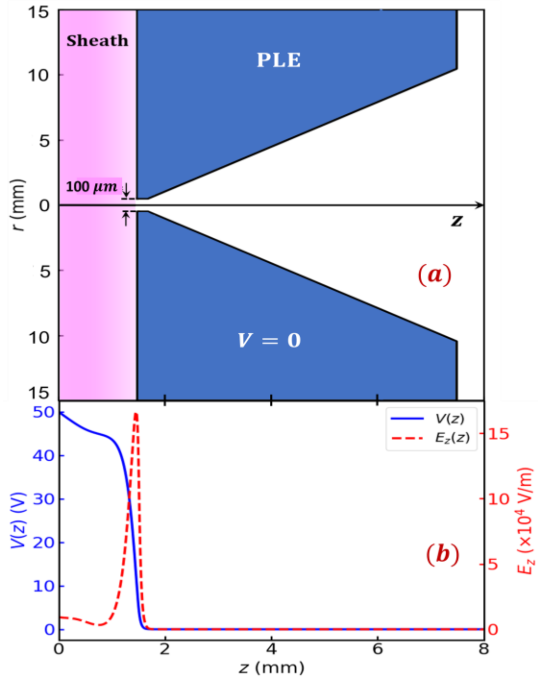

Fig. 2. (a) PLE aperture, (b) Variation of *V* and E_z along the *z* axis.

The focal length of an aperture lens is given by[1],

$$f = \frac{4T}{q(E_{z2}-E_{z1})}, \quad (1)$$

where q and T are the charge and kinetic energy of the ions respectively, E_{z1} and E_{z2} are the axial electric fields on the both side of the aperture. The *DM* of the combined lens system in the MEFIB is calculated using optical methods where the main lenses are considered as thick lenses, and the beam blanking aperture as thin lens. The *DM* is calculated for different PLE aperture sizes and for different λ_d, which can be realized by varying the discharge power and pressure. The results will be presented in the conference.

Work supported by SERB (DST), Government of India.

References

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