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The study of negative ion beam optics in a hydrogen negative ion source by using 3D3V PIC simulation

3D3VPICシミュレーションを用いた水素負イオン源における負イオンビーム光学の研究

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The physical mechanism of negative ion extraction under real conditions with the complicated magnetic field is studied by using the 3D3V PIC simulation code. It is shown that the *E* x *B* drift of electrons is caused by the magnetic filter or the electron suppression magnetic field, and the resultant asymmetry of the plasma meniscus. Furthermore, it is indicated that that the asymmetry of the plasma meniscus results in the asymmetry of negative ion beam profile.

1. Introduction

Negative ion based neutral beam injection system (N-NBI system) is one of the promising candidates for plasma heating and current drive of magnetic fusion reactors. The negative ion source which can produce negative ion beams with high power and long pulse is the key component for the N-NBI system. One of the essential issues for the design and development of such a negative ion source is to clarify negative ion trajectories in the cesiated volume ion source, especially to understand the physics of the beam halo formation.

In order to clarify the mechanism of negative ion extraction under real conditions with the complicated magnetic field and analyze the beam halo quantitatively, the 3D simulation code [1] has been developed. For a negative ion source, the plasma meniscus can be defined as the surface where electron and negative ion saturation current densities are equal to their space charge current densities. Thus, the plasma meniscus strongly depends on electron loss along/across the magnetic field line. Especially, it is pointed out in other PIC simulations that the asymmetry of the plasma density profile is caused by the *E* x *B* drift and/or diamagnetic drift under the magnetic fields [2-4]. In the present study, the influence of the magnetic fields on the source plasma and negative ion beam optics will be reported.

2. Simulation Model

The simulation model in the present study is almost the same as the previous 3D3V (three-dimensional in the real space and there-dimensional in the velocity space) PIC model [1]. The extraction region of the negative ion source is modelled with 3D geometry. The simulation domain includes the plasma grid (PG) with a single aperture. An overall view of the 3D PIC model is shown in Fig.1. The *x*-axis is taken to be the direction of the H^- extraction. The magnetic filter and the electron suppression magnetic field are taken into account. The *y*-axis is parallel to the direction of the electron suppression magnetic field, while the *z*-axis is parallel to the direction of the magnetic filter. The typical strengths of the magnetic filter and electron suppression magnetic field near the exit of the PG are 40 Gauss and 300 Gauss, respectively.

The main physical parameters in the source region are summarized in Table I. The surface produced H^- ions are launched uniformly from the PG surface with the half-Maxwellian distribution.

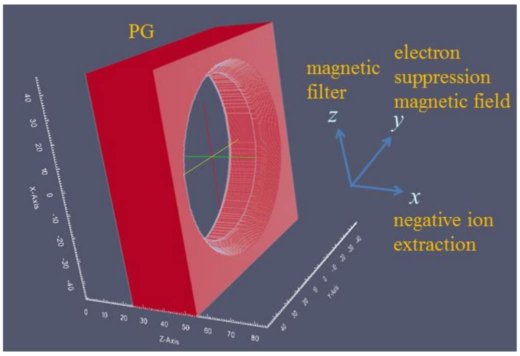

Fig.1. An overall view of the 3D PIC model

Table I. Main Physical parameters in the source region

Physical Parameter	Value
Electron Temperature	1 eV
Hydrogen Ion Temperature	0.25 eV (H^+ ion, volume produced H^-)
Electron Density	1x 10^{18} m^{-3}

Electron-neutral and Coulomb collisions are taken into account through the electron diffusion across the magnetic fields. A simple diffusion model [5, 6] is employed, in which a random-walk process with step lengths $\Delta\tilde{x}_d$ is given by

$$\Delta\tilde{x}_d = \sqrt{2\tilde{D}_\perp \Delta\tilde{t}} \times \xi_x \times \sqrt{\tau_{//}/\tau_\perp}, \qquad (1)$$

where $\tilde{D}_\perp, \Delta\tilde{t}$, and ξ_x are a normalized perpendicular diffusion coefficient, a time step, and a normal random number. In eq. (1), $\tau_{//}$ is the characteristic time of electron escape along the magnetic field, while $\tau_\perp$ is the characteristic time of the electron diffusion across the magnetic field.

3. Result

The density profiles at $\tilde{z} = 0$ in the *x-y* plane, which is parallel to the magnetic filter, are shown in Fig.2 for (a) electron and (b) H^- ion around the PG.

In this situation, the H^- current density and the ratio of the electron current density to the H^- current density are estimated to be 19.6 mA/cm^2 and 18.7, respectively. The location of the plasma meniscus is indicated as a green line in Fig.2 (b).

It is obviously shown that the density profile of electron is asymmetric near the PG although it is symmetric in the source plasma region, for example, $\tilde{x} = 10$. This asymmetric density profile near the PG is caused by the *E* x *B* drift, where *E* is an electric field for the extraction of negative ions, and *B* is the magnetic filter. The plasma meniscus can be defined as the surface where electron and negative ion saturation current densities are equal to their space charge current densities. Thus, the asymmetry of electron density profile results in the asymmetry of the shape of the plasma meniscus.

The negative ion beam profile along the line of $\tilde{x} = 70$ in Fig.2 is shown in Fig.3. The negative ion beam profile is asymmetric. For example, as shown in red curves, the negative ion current density on the upper side of this profile ($\tilde{y} > 0$) is larger than that on the lower side ($\tilde{y} < 0$). Moreover, as shown in the blue curves, the tail on the lower side of this profile is broadened slightly compared with that on the upper side. This asymmetry of the negative ion beam profile is caused by the curvature of the plasma meniscus.

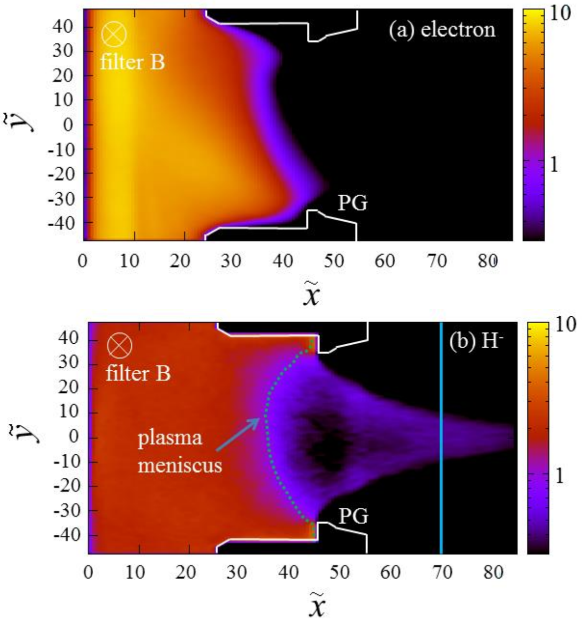

Fig.2. The density profiles of (a) electrons and (b) H^- ions in the *x-y* plane

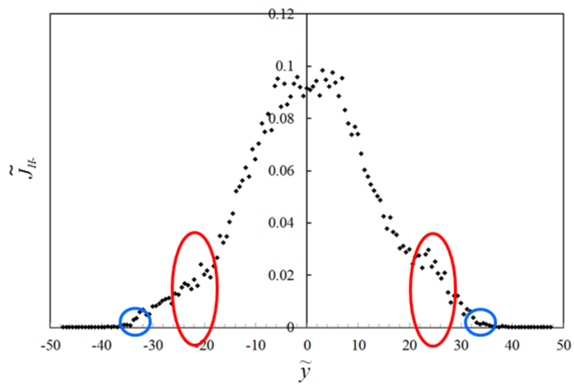

Fig.3. The negative ion beam profile along the line of $\tilde{x} = 70$ in Fig.2.

Similarly, due to the *E* x *B* drift, the asymmetries of plasma density and H^- beam profiles are also observed on the *x-z* plane which is perpendicular to the electron suppression magnetic field.

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