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Study of Plasma Meniscus Formation and Beam Halo in Negative ion Source Using 3D3VPIC Model
水素負イオン源におけるプラズマメニスカスおよびビームハロに関する 3D3VPIC Modelを用いた研究

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Abstract. In this study, the effects of the electron confinement time on the plasma meniscus and the fraction of the beam halo are investigated by 3D3V-PIC (three dimension in real space and three dimension in velocity space) (Particle in Cell) simulation in the extraction region of negative ion source. The electron confinement time depends on the characteristic time of electron escape along the magnetic field as well as the characteristic time of diffusion across the magnetic field. Our 3D3V-PIC results support the previous result by 2D3V-PIC results i.e., it is confirmed that the penetration of the plasma meniscus becomes deep into the source plasma region when the effective confinement time is short

1. Introduction

Negative ion based neutral beam injection (N-NBI) system is one of the promising candidates for heating and current drive in future fusion reactors. In the NBI-System, the negative ion sources are required to produce high energy, high current density and long pulse negative ion beams.

One of the key issues for the design and development of such negative ion sources is to suppress the heat load on the grid which caused by the beam halo. Therefore, to understand the physical mechanism of the beam halo formation is inevitable for the suppression of the beam halo and to realize the N-NBI system.

Recently, it has been shown that the effective electron confinement time significantly affect the formation of the plasma meniscus by 2D3V-PIC (two dimension in real space and three dimension in velocity space)・(Particle in Cell) simulation [1]. The electron confinement time depends on the characteristic time of electron escape along the PG magnetic field as well as the characteristic time of electron diffusion across this magnetic field.

The purpose of this study is to confirm the validity of above finding by 2D3V-PIC modeling. The effect of the effective electron confinement time on plasma meniscus formation and beam halo has been studied with 3D3V-PIC simulation.

2. Simulation Model

We have developed numerical simulation model with 3D3V-PIC method for the extraction region in JT-60 negative ion source [5]. The present 3D3V-PIC model is based on a series of the 2D3V-PIC modeling [1, 3, 4, 5], which has been done step-by-step in order to validate carefully physics and numerical models used in the model.

The motion of charged particles (H^+ ions, H^- ions, and electrons) is solved in their self-consistent electric field by using the PIC method. The 3D trajectory is first calculated with the equation of motion for each particle. The Poisson's equation is then solved at each mesh point to obtain the electric potential.

The extraction region of the negative ion source is modeled with a 3D geometry. Figure 1 shows geometry of our 3D simulation model. The simulation domain includes the Plasma Grid (PG) with single aperture. The *x*-axis is taken to be the direction of H^- extraction, while *z*-axis is parallel to the direction of the PG magnetic filter. The PG magnetic field is taken from ref. [6].

In the extraction region, electrons can diffuse across the PG magnetic filter field due to Coulomb collisions. However, electrons can escape along the magnetic field much faster than diffuse across the magnetic field. Therefore, the effect of the electron

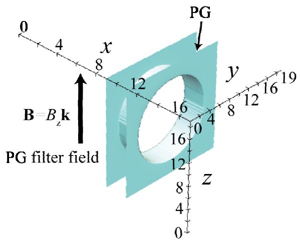

Figure 1. 3D geometry of simulation domain.

confinement time is taken into account by changing the parameter $\sqrt{\tau_{//}/\tau_{\perp}}$ which is used in the equation shown below

$$\Delta x_d = \sqrt{2D_{\perp}\Delta t} \times \xi_x \times \sqrt{\tau_{//}/\tau_{\perp}}, \quad (1)$$

where Δx_d , $\Delta t, D_{\perp}$, and ξ_x are the step length of random-walk process, the time step, diffusion coefficient across the magnetic field, and a normal random number, respectively. In Eq. (1), $\tau_{//}$ and $\tau_{\perp}$ are the characteristic time of electron escape along the magnetic field and the characteristic time of the electron diffusion across the magnetic field, respectively.

3. Results and Discussion

Figure 2 shows the H^- density profiles in *x-z* mid plane for (a) $\sqrt{\tau_{//}/\tau_{\perp}}$ = 0 and (c) $\sqrt{\tau_{//}/\tau_{\perp}}$ = 0.016 in *x-z* mid-plane which is parallel to PG filter field at *y*=9.5mm. In those figures, the broken line shows the contour of gradϕ=0. Generally, this contour defines a plasma meniscus. The H^- ions are started accelerating towards the extraction grid outside the ion source from this contour.

As seen from the comparison of Fig. 2 (a) and (b), the penetration of the plasma meniscus into the source plasma for $\sqrt{\tau_{//}/\tau_{\perp}}$ = 0.016 is shallower than that for $\sqrt{\tau_{//}/\tau_{\perp}}$ = 0. This tendency agrees well with the result by 2D3V-PIC model in Ref. [1]. The reason why the penetration of the plasma meniscus is shallow for the large value of $\sqrt{\tau_{//}/\tau_{\perp}}$ is explained by following manner:

(1) Electron density in front of the PG is increased due to the electron loss along the magnetic filter field because of the large $\tau_{//}$, i.e. small electron loss along the magnetic field line.

(2) Therefore, the effect of the Debye shielding by electrons become also large.

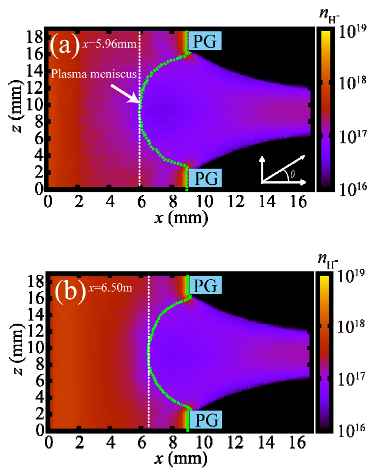

Figure 2. 2D H^- density profile and the plasma meniscus in x-y mid plane for the case (a) $\sqrt{\tau_{//}/\tau_{\perp}} = 0$ and (b) $\sqrt{\tau_{//}/\tau_{\perp}} = 0.016$ respectively

(3) Debye shield by the H^- ions considered to be smaller than that by the electron due to their small mobility.

From these results, the ratio of beam halo to the beam core component is calculated 11.02% in Fig. 2 (a), 5.18% in Fig. 2 (b), respectively. The reason why the ratio of the beam halo is reduced for the large value of $\sqrt{\tau_{//}/\tau_{\perp}}$ is the shallow penetration of the plasma meniscus as shown in Fig. 2.

From the above comparisons, the dependence of the plasma meniscus and beam halo on the effective electron confinement time has been confirmed also by 3D3V-PIC simulation as in 2D3V-PIC simulation observed. Therefore, the strength of magnetic filter and the size of the arc chamber which has effects on electron confinement time are important for design of the negative ion sources to suppress the fraction of the beam halo.

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