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Numerical Simulation of Negative Ion Extraction in Negative Hydrogen Ion Sources
水素負イオン源における負イオン引き出しの数値シミュレーション

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The modeling and analysis of a negative ion source has been done by using a 2D particle-in-cell simulation. The effect of the H^- ion surface production process on the plasma grid (PG) surface is investigated. It is shown that with the increase of H^- ion particles from the PG surface, the H^- ion current density is enhanced, while the electron current density decreases. These results agree well with the experimental results observed in typical negative ion sources. Moreover, it is found that plasma quasi-neutrality holds mainly by both H^+ and H^- ions in the bulk plasma around the PG.

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. It is essential for the development of such a negative ion source to suppress heat loads of the acceleration grids and beamline components[1]. To suppress heat loads, it is important to understand the formation the mechanism of meniscus and H^- extraction process in negative ion sources, because the meniscus of source plasma-ion beam boundary largely affects the H^- ion beam optics.

The meniscus is determined from the sheath potential near the plasma grid (PG), and the electric field for H^- ion extraction. In order to produce high current H^- ions, Cs vapor is seeded into most of tandem-type negative ion sources [2-3]. The Cs layers absorbed on the surface of plasma grid (PG) result in low work function of the PG surface, followed by the surface production of H^- ions. Thus, there exists a large amount of H^- ions near the PG surface. Under this physical situation, formation mechanism of meniscus and H^- extraction process is not clearly understood.

We have developed Particle-cell (PIC) code to study the extraction mechanism of H^- ions for the H^- volume production [4]. The purpose of this study is 1) to improve this 2D PIC model by taking into account H^- surface production, and 2) to perform a simulation under the case where the strong surface production takes place.

2. SIMULATION MODEL

The motion of the charged particles (electrons, H^+ ions, and H^- ions) is solved by using the PIC method. The trajectories of each particle are calculated with the equation of motion:

$$m\frac{d\mathbf{v}}{dt} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \qquad (1)$$

where *m*, ***v***, *q*, ***E***, and ***B*** are mass, velocity, electric charge, local electric field, and magnetic field. The equation of motion is solved by using the Boris-Buneman version of the leap-frog method.

The charge density is obtained at each mesh point from the particle location by using a linear interpolation. The Poisson equation is then solved at each mesh point.

$$\nabla^2 \varphi = q(n_{H^+} - n_{H^-} - n_e)/\varepsilon_0 \qquad (2)$$

where n and ε_0 are the density of each particles and the permittivity of vacuum, respectively.

Physical quantities are practically normalized. The detail definitions are given in the Ref. [5].

Figure 1 shows the model geometry used in the present PIC modeling. In our study, we model the extraction region of the source with a simple 2D geometry. The *x*-axis is taken parallel to the direction of the extracted beam, while the *y*-axis is parallel to the PG surface. Normalized potentials at $\tilde{x} = 0$ and $\tilde{x} = \tilde{x}_{\max}$ are 0 and 180, respectively.

At $\tilde{t} = 0$, H^+ ions, electrons, and H^- ions are loaded in the source region at the rate of N_{H+}: N_e: N_{H-}= 10: 9: 1. When H^+ ions are passed through the PG or $\tilde{x} = 0$ boundary, a pair of H^+ ion and electron is reloaded in the source region. The other particles passing through these boundaries are removed. All the particles passing through $\tilde{x} = \tilde{x}_{\max}$ boundary are reloaded in the source region. All the particles passing through $\tilde{y} = 0$ or $\tilde{y} = \tilde{y}_{\max}$ boundary are reflected into model region. The surface produced H^- ions are modeled to be launched at the surface of the PG with the initial energy of a few eV.

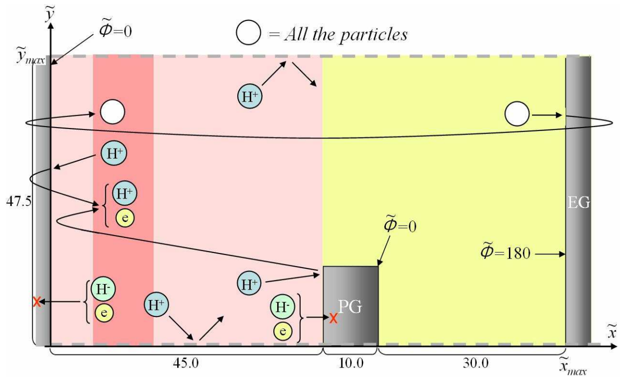

Fig.1. The schematic view of the simulation model.

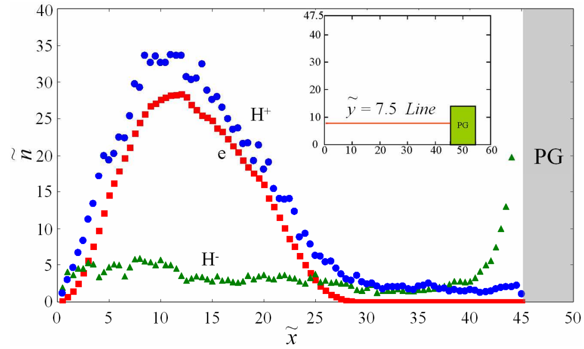

Fig.3. The plot of the density profile of each particles in the *x*- direction.

3. RESULT

The time evolutions of the extracted H- ion current and the electron current are shown in Fig. 2. The number of launched H- ions from the PG surface is (a) 1 particle, and (b) 5 particles per time step, respectively. In both cases, H- injected from the PG surface is started at $\tilde{t} = 1.0\times10^4$ in Fig. 2.

In Fig. 2, H- current density with surface production increases from the one without surface production, while electron current density decreases. Moreover, the H- ion current density in the case (b) is twice higher than in the case (a), while the electron density in the case (b) is about half as high as in the case (b). This means that the H- ion current density is enhanced as the Cs effect, and the electron current density decreases as the Cs effect.

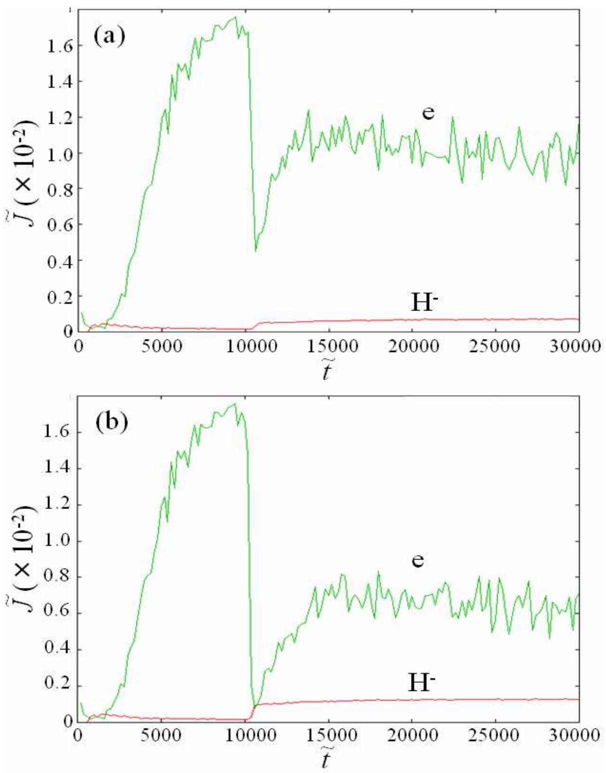

Fig.2. The time evolutions of the extracted H- ion current and the electron current.

Figure 3 shows the density profiles of electron, H^+, H^-. These profiles are obtained along the line $\tilde{y} = 7.5$ in Fig.1 parallel to the *x*-axis. The profiles have been obtained by averaging over the period of $2.8\times10^4 \leq \tilde{t} \leq 3.0\times10^4$ in Fig. 2 (b). As seen from Fig. 3, electrons do not exist in front of the PG surface while H^+ and H^- ions equally exist (especially $30 \leq \tilde{x} \leq 40$). This means that the plasma quasi-neutrality is hold by a pair of ions in front of PG surface. In addition, it should be noted that the thickness of the H^+ and H^- ion layer is relatively large ($\geq 10\lambda_D$). These results agree well with the typical experimental results in seeding Cs into negative ion sources [6].

4. CONCLUSION

The modeling and analysis of a negative ion source has been done by using a 2D PIC model with taking account of H- surface production. It is shown that with the increase of surface produced H- ions, the H- ion current density is enhanced, while the electron current density decreases. Moreover, it is shown that plasma quasi-neutrality holds mainly by H^+ and H^- ions in front of the PG surface. These results agree with the typical experimental results. Although the model is still under the improvement, the present results show that the model is useful for analyzing plasma transport, electrostatic potential structure closed to the PG, and H- extraction under the strong H- surface production.

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