20PA-026

Electrostatic Oscillation in Double-ion Plasma Layer of a Negative ion source

水素負イオン源におけるダブルイオンプラズマ中の揺動現象

Ippei Goto, Shu Nishioka, Kenji Miyamoto and Akiyoshi Hatayama
後藤一平[1], 西岡宗[1], 宮本賢治[2], 畑山明聖[1]

1. *Graduate school of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522,Japan*
2. *Naruto University of Education, 748 Nakashima, Takashima, Naruto-cho, Naruto-shi, Tokushima 772-8502, Japan*
慶應義塾大学理工学部理工学研究科　〒223-8522 横浜市港北区日吉3-14-1
鳴門教育大学 〒772-8502 徳島県鳴門市鳴門町高島中島748

We have developed a 2D3V-PIC model of the extraction region, aiming to clarify the basic extraction mechanism of H^- ions from the double-ion plasma in H^- negative ion sources. Relatively slow electrostatic oscillation compared with the electron plasma frequency has been observed in the extraction region. Results of the systematic study using a 1D3V-PIC model with the uniform magnetic field confirm the result that the electrostatic oscillation is identified to be lower hybrid wave. The effect of this oscillation on the H^- transport will be studied in the future.

1. Introduction

Negative hydrogen ion sources have been developed for neutral beam injectors of thermonuclear fusion devices. The negative ion source, which can produce high power and high current with long pulse, is necessary for the future large scale thermonuclear fusion reactors such ITER. Cs-seeded H^- sources can produce high current negative ion beam. However, negative ion extraction is not been optimized yet. Studies using the 2D3V-PIC (two dimension in real space and three dimension in velocity space)·(Particle In Cell), and 3D3V-PIC (three dimension in real space and three dimension in velocity space) model have been done, aiming to understand the extraction mechanisms of H^- ions from the negative ion source [1-3, 4]. However, the extraction mechanisms have not been completely clarified yet. Double-ion plasma layer, which is consisting of H^+ and H^- ions, has been observed in the vicinity of Plasma Grid (PG) of Cs-seeded H^- negative ion sources[4]. Recent experiments show that H^- density n_{H-} in the upstream region away from the plasma meniscus (H^- emitting surface) has been reduced by applying the extraction voltage[5, 6]. This fact indicates that H^- ions in the double-ion plasma layer even far from the PG are extracted, although the extraction voltage is shielded by the Debye shield effect. In our previous study by using 2D3V-PIC model, the potential oscillations are observed in extraction region. In this paper, the identification of the oscillation observed in the simulation will be done.

2. Numerical model

The details of the 2D3V PIC model is described else where[1-4]. The simulation geometry and the boundary conditions of the model are shown in Fig. 1. The boundary conditions of at $\tilde{y}=\tilde{y}_{\min},\tilde{y}_{\max}$ are set to be the periodic boundary conditions. The simulation domain contains one extraction hole including the plasma grid (PG) and the extraction grid (EG), and 34 mm from the inner surface of EG has been modeled. The PG filter magnet field has been applied to the $\tilde{y}$-direction. The $\tilde{x}$-axis is taken to be the direction of the H^- ion extraction.

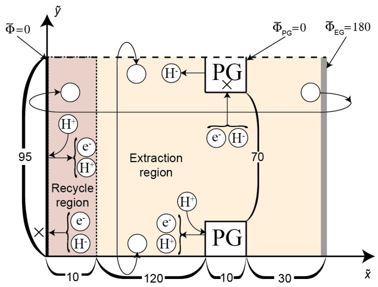

Fig.1. Simulation domain and boundary conditions.

3. Results and Discussion

3.1 *Electrostatic wave in the extraction region*

The time evolution of the electric potential on the quasi-steady states at 10 mm far from the inner surface of the PG and on the center axis in the *y*-direction has been analyzed by Fast Fourier Transform (FFT) method, and the result is shown in Fig. 2. As shown in Fig. 2, a strong peak at

$f = 3.10 \times 10^7$ Hz has been observed. This electrostatic oscillation propagates perpendicular to the magnetic field toward the PG aperture. The electrons are not allowed to preserve charge neutrality because they are strongly magnetized with small Larmor radius. In this situation, Lower Hybrid Wave (LHW) can be excited. The frequency of LHW is described by the following formula,

$$\omega_{\rm L} = \sqrt{\omega_{\rm ce} \cdot \omega_{\rm ci}}, \qquad (1)$$

The symbol $\omega_{\rm ce}$ and $\omega_{\rm ci}$ in Eq. (1) are electron and H^+ ion cyclotron frequencies, defined by following equations,

$$\omega_{\rm ce} = \frac{eB}{m_{\rm e}}, \quad \omega_{\rm ci} = \frac{eB}{m_{\rm i}},$$

where, e, me, mi, B are electric charge, mass of electron, mass of H^+ ion and magnetic field strength, respectively.

The frequency of LHW strongly depends on the magnetic field strength. In this 2D3V-PIC simulation, however, the magnetic field is specially varied. Due to this spatial variation, the frequencies of LHW $f_{\rm L} = \omega_{\rm L}/2\pi$ are in the range of about $4.5 \times 10^6 < f_{\rm L} < 8.5 \times 10^7$ Hz from Ep. (1) in the extraction region, depending on the distance from the PG. The frequency of the electrostatic oscillation observed in this simulation falls in the frequency range of LHW mentioned above. Therefore the wave observed in the simulation is considered to be LHW.

In order to confirm this idea, we have done more simple but more systematic calculations with constant magnetic field in the following section.

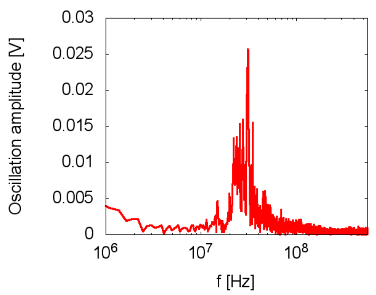

Fig.2. Spectrum of potential oscillation.

3.2 *Frequency Analysis by 1D3V-PIC*

In this simple 1D3V-PIC model, $\tilde{x} = 0$, 100 are taken the calculation boundaries with Φ=0 in the $\tilde{x}$-direction. On the other hand, the system length in the $\tilde{y}$-direction is taken to be infinite. The direction of the magnetic field is taken to be in the $\tilde{y}$-direction. The magnetic field has been assumed to be uniform for whole domain in this simple model. The strength is taken as a parameter, B =100, 200, 300, 400, 500 for each run. The remaining conditions are kept constant as those in the 2D3V-PIC model. Under these conditions, the frequency of LHW takes a single value, depending on the magnetic strength value. The time evolution of the electrostatic oscillations at $\tilde{x} = 50$ has been analyzed by FFT method. Figure 3 shows the comparisons of the wave frequencies between the theoretical value and the simulation result. The values of the frequencies of the waves obtained in the simulation model well agree with the theoretical values of LHW. Therefore the electrostatic oscillation observed in the simulation has been identified as LHW. These simulation results by the simple model confirm the idea that the electrostatic oscillation observed in above 2D3V simulation is identified as LHW.

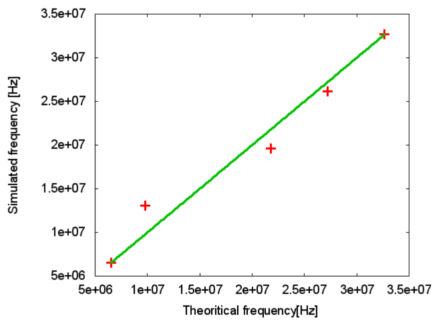

Fig.3. Wave frequencies by simulation and theoretical value.

4. Conclusion

Electrostatic oscillations have been observed in the extraction region. The electrostatic oscillation observed in the extraction region has been identified as LHW by the systematic study with constant magnetic fields by using the 1D3V-PIC model. The detailed analysis of H^- transport due to this kind of potential oscillation will be done in the near future.

References

[1] K. Miyamoto, S. Okuda, A. Hatayama, and M. Hanada, Rev. Sci. Instrum., 83, 02A723 (2012).

[2] K. Miyamoto, S. Okuda, S. Nishioka, and A. Hatayama, J. Appl. Phys., 114, 103302/1-7 (2013).

[3] K. Miyamoto, S. Okuda, S. Nishioka, and A. Hatayama, J. Appl. Phys., 114, 103302/1-7 (2013).

[4] S. Kuppel, D. Matsushita, A. Hatayama, and M. Bacal, J. Appl. Phys. 109, 13305 (2011).

[5] K. Tsumori, H. Nakano, M. Kisaki, K. Ikeda, K. Nagaoka,*et al.*, Rev. Sci. Instrum., 83, 02B116 (2012).

[6] K. Ikeda, H. Nakano, K. Tsumori, M. Kisaki, K. Nagaoka, *et al.*, New J. Phys., 15, 103026 (2013).