§11. Integrated Modeling of Negative Hydrogen (H^-/D^-) Ion Production, Extraction and Acceleration in a Large Negative Ion Source for Neutral Beam Injection System

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In N-NBI (Negative-ion-based Neutral Beam Injector) system for large fusion devices such as LHD, the optimization of 1) negative ion (H^- /D^-) production, 2) H^- /D^- extraction from the source, and 3) H^-/D^- beam acceleration towards the target are the key R&D items to obtain intense high power N-NBI beam for plasma heating.

For the optimization of the H^-/D^- extraction from the extraction hole, it is indispensable to understand the formation mechanism of the ion emissive surface (so-called plasma meniscus) and its location/shape around the extraction hole. Recently, in the NIFS-R&D ion source which is scaled down with a half size of the LHD ones, the following interesting experimental observation has been reported under the "surface" H^- production case with the Cs-seeding[1)] : Plasma layer consisting of H^+ and H^- ions (i.e., electrons are excluded from the layer) is formed in the vicinity of the plasma grid (PG). Such plasma with positive and negative hydrogen ions is called "double-ion plasma", and it could have strong influences on the formation mechanism of plasma meniscus.

In the previous study, we developed the 2D3V PIC (Two Dimensional in real space and Three Dimensional in velocity space Particle-in Cell) model[2, 3)] to analyze the electrostatic potential structure in the extraction region self-consistently with the charged particle dynamics. In this study, we start improving the model from the 2D to the 3D model in order to check the 2D results with those by the 3D model.[4)] As a first step, a relatively simple geometry with only one extraction aperture in Fig.1 has been used.

In Fig.2, the plasma meniscus shapes (green line) have been compared between the 2D and 3D result under the strong surface H^- production on the PG. In both cases, the plasma meniscus has a curvature near the PG. It is verified by the 3D model as well as the previous 2D model that the beam-halo component is produced by this curvature and the resultant over-focusing of the extraction beam. However, the fraction of the beam halo to the total beam current is small in the 3D result (~2% in Fig.3) compared with the 2D result, because the curvature near the PG in the 3D case is smaller than in the 2D case in Fig.2. Quantitatively more reasonable agreement with the experiments has been obtained by the 3D model.

For further understanding of the formation mechanism and control of the plasma meniscus, more detailed 3D modeling and comparison with the experimental results are now underway.

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2) T. Fukuyama, S. Okuda, A. Fukano, K. Tsumori, H. Nakano, A. Hatayama, AIP Conf. Proc. **1515**, 74 (2013).
3) K. Miyamoto, S. Okuda and A. Hatayama, Appl. Phys. Lett. **100**, 233507 (2012)
4) S. Nishioka, K. Miyamoto, S. Okuda, I. Goto, *et al.*, Rev. Sci. Instrum., **85**, 02A737 (2014).

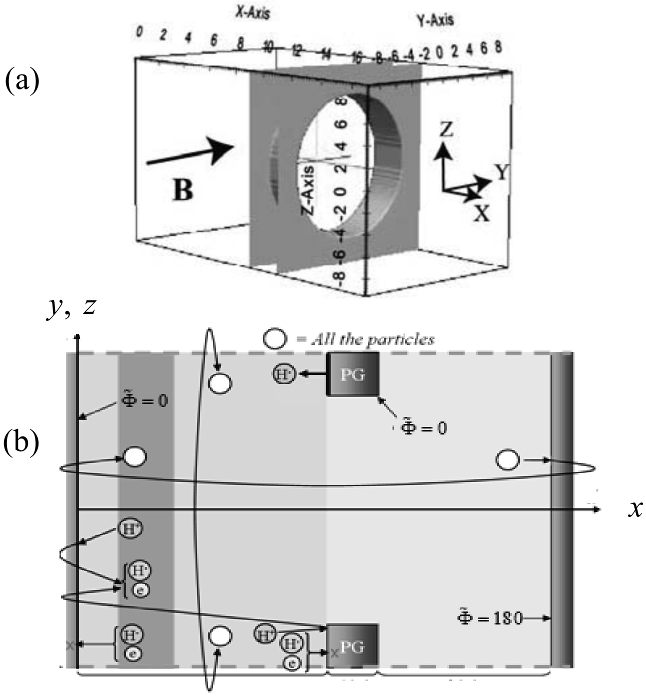

Fig. 1 3D3V PIC model for the extraction region in the H^- ion source: (a) Model geometry, and (b) Boundary conditions used in the simulation.

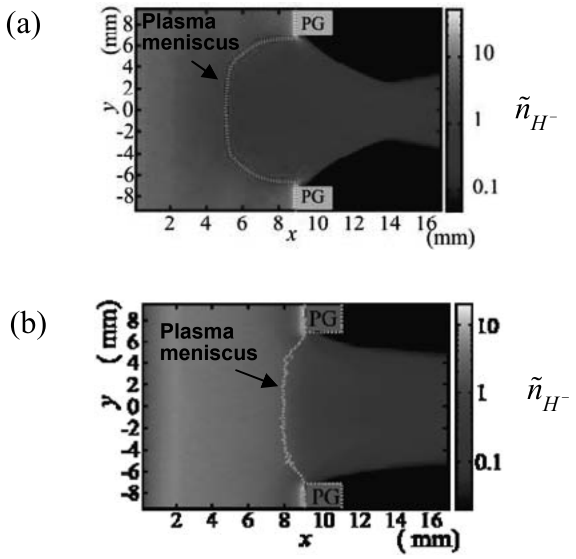

Fig. 2 Normalized H^- density profile in the extraction region calculated by (a) 2D3VPIC model, and (b) 3D3VPIC model.

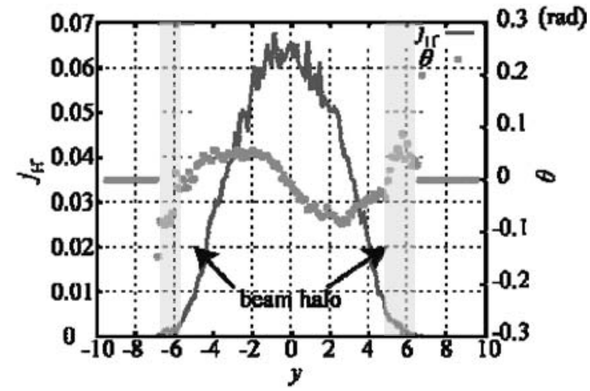

Fig.3 Emittance diagram of extracted H^- beam at x=x_{max}.