§14. Flow of H^- Ions in a Cs-seeded Negative Hydrogen Ion Source for NBI

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Negative ion based neutral beam injector (N-NBI) is a reliable device for effective plasma heating and current drive for a fusion device due to its high neutralization efficiency at high beam energy and low beam divergence. In a negative hydrogen ion source, Cs is seeded into the plasma to enhance the production of H^- ions which are mainly produced on the surface of the plasma grid. However, the extraction mechanism is unknown since the initial direction of surface produced H^- ions is opposite to the beam direction. Two possibilities have been proposed for the extraction of H^- ions: (1) extracted H^- ions are produced on the conical surface of the extraction aperture and extracted directly from this conical surface and (2) H^- ions are produced on the plasma grid surface facing to the plasma, flow to the plasma, and turns to the extraction aperture. In the case of mechanism (1), a beam halo will be introduced.[1] However, the beam halo was not observed by the beamlet monitoring experiments.[2] In addition, experiments by H_α image[3] do not support the mechanism (1). Therefore, mechanism (2) is a preferable candidate. Experiment about H^- ion flow in Cs seeded negative hydrogen ion source has been conducted to confirm the mechanism (2).

In order to measure the H^- ion flow, photodetachment and a four-pin directional Langmuir probe were utilized.[4] The thermal velocity and flow velocity were determined by the recovery time at two opposite probe tips.[5] During laser irradiation, H^- ions in the laser column are detached to H atoms and electrons. After the laser irradiation, these electrons are collected by the probe tip and the surrounding H^- ions flow to the photodetachment region to recover to the original plasma state. The recovery time is the arrival time of H^- ions from the boundary of the photodetachment region to the probe tip and it is dominated by flow velocity and thermal velocity. The recovery speed can be calculated by the recovery time. In the plasma, the recovery speeds at two opposite probe tip are different due to the shading effect of the probe stem. Thermal velocity and flow velocity can be determined from this difference. According to the thermal velocity, the H^- temperature has been estimated to be ~0.12 eV which is consistent with the cavity ring-down measurement. The evaluated flow velocity is one order lower than the thermal velocity.

The measured two-dimensional H^- flow pattern during beam extraction is shown in Fig. 1. In total, there are 12 measurement points. Interpolation was carried out in order to obtain more details. The flow pattern shown in Fig. 1 is based on the interpolated data. It can be found that H^- ions are produced on the surface of the plasma grid and flow to the plasma. Far away from the plasma grid (z>19 mm), the flow suggests two possibilities of the H^- ion flow: (a) H^- ions are produced on the grid metal and travel along a curve path to the plasma, and (b) H^- ions are produced on the neighbor grid metal, and experience long distance travel to the plasma. H^- ions turn to the extraction aperture at ~20 mm apart from the plasma grid.

A possibility for the position of the stagnation point of the H- flow is that H^- ions are influenced by the electron deflection magnetic field (EDM field) which is applied to the extraction grid to remove electron component from the extracted beam. The EDM field can penetrate to the plasma. Two-dimensional plasma profile indicated that the boundary of the EDM field is ~10 mm apart from the plasma grid. The Larmor radius of H^- ion is ~10 mm in this region. H^- ions flow along the EDM field, and turn to the extraction aperture at ~20 mm apart from the plasma grid.

The two-dimensional flow pattern confirms the extraction mechanism (2). The low H^- temperature is one of the evidences that the H^- beam has low beam divergence angle.

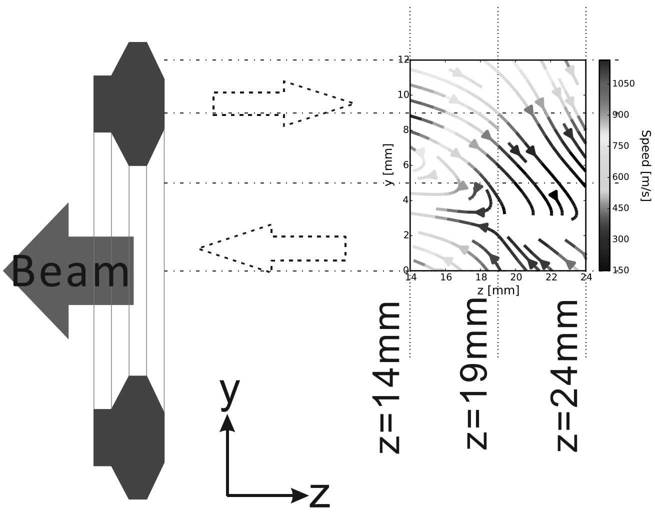

Fig. 1. Measured H- flow pattern near the plasma grid. Position 0 in y direction indicates the central axis of the extraction aperture.

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2) Tsumori, K. et al.: Rev. Sci. Instrum. 87 (2016) 02B936.
3) Ikeda, K. et al.: New J. Phys. 15 (2013) 103026.
4) Geng, S. et al.: Rev. Sci. Instrum. 87 (2016) 02B103.
5) Kado, S. et al.: Plasma Phys. 46 (2006) 367.