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Characteristics of the extracted negative-ion beam in a cesium-free negative-ion source using TPDsheet-U

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This study reports a progress toward realizing a high performance Cs-free negative ion source, that produces negative ions by volume production in a magnetized-sheet plasma device (TPDsheet-U). The experimental results show that this performance of the current density of the negative hydrogen ion beam $\mathcal{J}_c$ without Cs on TPDsheet-U is a pproximately comparable to that of the negative ion source on ITER-NBI with Cs. Experimental observations show that (i) negative hydrogen ions are successfully extracted from the sheet plasma by single/multi-aperture grids, and (ii) the ratio of the extracted electron current I_{EG}(e) and hydrogen negative-ion current I_C(H-), I_{EG}(e)/I_C(H-) decreases from 5.0 to 1.0 with an increase in the height of the electron fence (H_{EF}), which is a physical filter that prevents electron diffusion from the extraction region. The $\mathcal{J}_c$ is approximately 10-20 mA/cm^2 at the extraction voltage V_{EX} of 9.0 kV, the discharge current I_d of 80 A, the gas pressure of 0.3 Pa, and the magnetic field strength of 40 mT.

Most NBI systems in fusion devices use surface production with Cs. Without Cs, the current density that is based on volume production is < 2 mA/cm^2. If it is operated with Cs, the source can deliver a negative ion current density of over 20 mA/cm^2, which is 10–15 times higher. However, careful Cs control is required for the continuous operation of the NBI, which must be also regularly maintained. Thus, it is important to find alternative materials or to develop Cs-free methods.

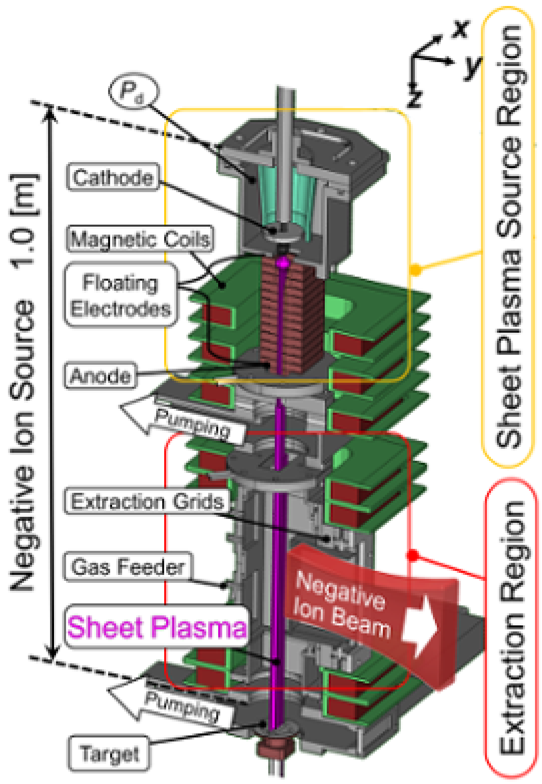

Figure 1: Schematic diagram of the Cs-free negative ion source using TPDsheet-U.

To produce and control negative hydrogen ions in plasma, we proposed to use magnetized-sheet plasma, which is produced by TPDsheet-U [1-3]. Magnetized-sheet plasma is suitable for generating negative hydrogen ions during dissociative attachment processes because high-energy (10–15 eV) and low-energy (1 eV) electron regions are narrowly spaced (e.g., 10–25 mm). This study is a work in progress toward realizing a Cs-free negative-ion source. This paper presents the characteristics of the extracted ion beam current using

TPDsheet-U.

The experimental setup is a Cs-free negative-ion source using TPDsheet-U, which is schematically illustrated in Fig. 1. The hydrogen sheet plasma is introduced to the extraction region under the stationary magnetic field generated by rectangular coils and terminated by an electrically floating target. The discharge current is varied between 40 A and 80 A. The neutral pressure in the extraction region is controlled by feeding the secondary hydrogen gas at the pressure of approximately 0.3 Pa. To extract negative-ion beams, two different sets of grids are located in the extraction region (Fig. 1): single-aperture and multi-aperture extraction grids. The negative hydrogen ion beam is extracted by the two-grid extraction system [i.e., plasma grid (PG) and extraction grid (EG)] located at the periphery of the sheet plasma, as shown in Fig. 2. The diameter of PG is Φ 4 mm and that of EG is Φ 6 mm, and the gap between grids, d, is 4 mm. In the multi-aperture grid, each grid has 39 apertures, and the beam group is made of 13 × 3 apertures. With a field strength of 40 mT and V_{EX} of 3–10 kV, the extracted current densities $\mathcal{J}_c$ and $\mathcal{J}_{EG}$ are measured at the collector (C) and EG, respectively.

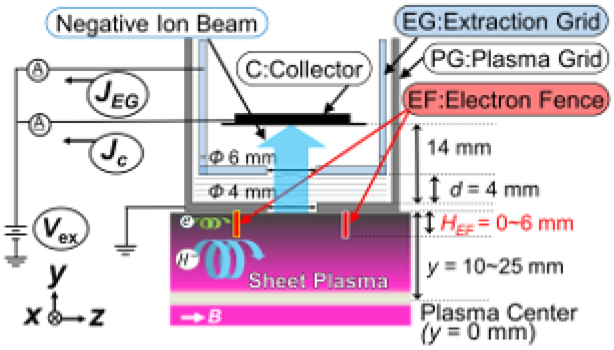

Figure 2: Schematic diagram of the extraction system electrodes: a two-grid extraction system is located at the periphery of sheet plasma. The electron fence (EF) bar is located on PG to suppress co-extracted electrons.

The extracted currents ($\mathcal{J}_{EG}$ and $\mathcal{J}_c$), as a function of discharge current I_d, with a single-aperture grid at V_{EX} of 3 kV, 6 kV, and 9 kV are shown in Fig. 3. The current of $\mathcal{J}_{EG}$ is the electron current, which is deflected onto EG by the external magnetic field. The current of $\mathcal{J}_c$ is the extracted negative-ion current. At V_{EX} of 9.0 kV and I_d of 80 A, $\mathcal{J}_c$ is 20 mA/cm^2. However, $\mathcal{J}_{EG}$ is five times larger than that of $\mathcal{J}_c$. An increase in the co-extracted electrons with a possibility of damaging the EG is an important issue to be solved in the negative-ion source.

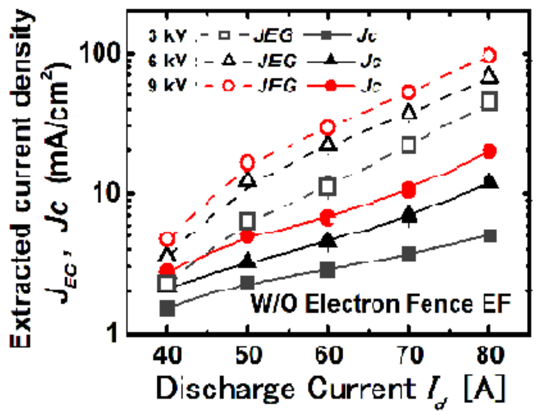

Figure 3: Extracted current density versus the discharge current at the extraction voltage of 9.0 kV. The gas pressure is fixed at 0.3 Pa, and the magnetic field strength is 40 mT. The current density of the negative hydrogen ion beam is 20 mA/cm^2 at the discarge current of 80 A.

The electron fence (EF) bar is located on PG to suppress co-extracted electrons (Fig. 2). The dependence of the ratio of the extracted electron current I_{EG}(e) and hydrogen negative-ion current I_C(H-), I_{EG}(e)/I_C(H-), on the height of the EF bar, H_{EF}, is shown in Fig. 4. I_d changes from 40 A to 70 A at V_{EX} of 9.0 kV. The ratio of

I_{EG}(e)/I_C(H−) gradually decreases with an increase in H_{EF} and is approximately 0.5–1.3. Near PG, electrons are trapped with the EF bar owing to the smaller gyro-radius of the electrons. The gyro-radius of hydrogen negative ions is larger than that of electrons, and hydrogen negative ions can pass through the electron fence bar. This result shows that electrons are effectively suppressed by the EF bar.

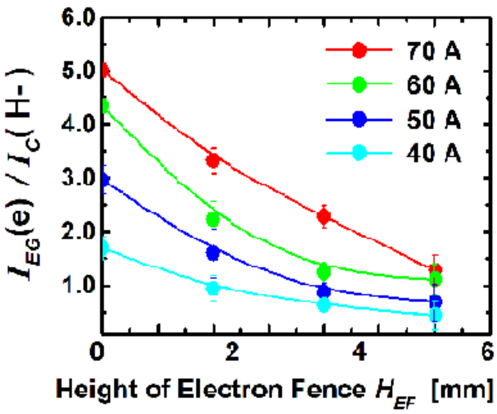

Figure 4: Dependence of the ratio of the extracted electron current and hydrogen negative-ion current in TPDsheet-U on the height of the EF bar. The discharge current changes from 40 to 70 A.

Multi-aperture grids have 39 holes to extract negative ions, which results in an increase in the extracted current depending on the number of apertures. In the multi-aperture setup with four EF bars (H_{EF} = 6 mm, 4 mm, 4 mm, 6 mm), the extracted negative ion beam current I_C increases with an increase in I_d. At an extraction voltage of 9.5 kV and a discharge current of 80 A, the current density of the negative hydrogen ion beam is approximately 23 mA. These shows that hydrogen negative ions are successfully extracted from sheet plasma.

This study indicates the importance of investigating the characteristics of extracted beam current in a magnetized-sheet plasma device (TPDsheet-U) without Cs and the possibility of achieving the continuous operation of the NBI without Cs.

References

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