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Production and beam extraction of H^- ions in a RF negative ion source
高周波負イオン源における水素負イオン生成とビーム引き出し特性

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A high density negative hydrogen/deuterium ion source based on RF plasma is required for ITER-NBI reference source. We utilized a MOSFET-based inverter power supply with lower frequency (~0.3 MHz) and high density RF plasma was produced. Produced H^- ions are extracted by DC high voltage up to 15 kV with cesium seeding into the source. Extraction and acceleration current increased with extraction voltage and RF power. Characteristics of high density negative hydrogen ion production and high voltage H^- beam extraction are presented.

1. Introduction

High density negative hydrogen ion sources are successfully developed for Neutral Beam Injection (NBI) sources for fusion devices [1,2]. For heating and current drive, ITER requires a 1 MeV negative deuterium (D^-) beam with pulse length of 3600 s and current intensity of 40 A with the source pressure of 0.3 Pa. RF ion sources are chosen as ITER reference sources for maintenance free, long pulse operation and low cesium (Cs) consumption operation.

Plasma production by using RF waves has been utilized in various industrial applications, where RF wave with the frequency of 13.56 MHz is often used. Relatively lower frequency of around 1 MHz is feasible for high density plasma production because of large skin depth. A RF ion source using around 1 MHz RF frequency has been operated successfully at IPP Garching [3,4]. Vacuum tube oscillator is conventionally used for the RF power supply for these high power operations. Recent development of metal oxide semiconductor field effect transistors (MOSFET) enables us to use an inverter circuit for RF power supply. This FET switching inverter power supply has the advantages of higher switching efficiency and easier frequency matching system compared to the vacuum tube based RF power supplies [5,6]. RF plasma production using a RF frequency lower than 1 MHz is somewhat difficult in low gas pressure because passing length of the accelerated electrons during one cycle of RF field becomes larger than the device scale. Validation of plasma discharge in low gas pressure using lower RF frequency is one of the main subjects in the experiment. We have successfully obtained an RF plasma in the pressure of 0.3 Pa without any help of gas puffing and filament emission for startup the discharge. In this paper, characteristics of H^- beam extraction from the RF ion source are presented.

2. Experimental set up

Figure 1 shows the schematic of the experimental setup for the experiment of a FET-based negative ion source. The ion source consists of a driver region and an expansion region. In the driver region RF plasma is produced in an Al_2O_3 ceramic tube (inner diameter: 70 mm, outer diameter: 80 mm, length: 170 mm). RF power (~0.3 MHz, ~20 kW, 5 ms) is applied to an antenna coil wound around the ceramic tube. RF matching is adjusted by LC circuit by changing the RF frequency and capacitance. In addition, an outer Helmholtz coil forms an axial magnetic field up to 22 mT. High density plasma

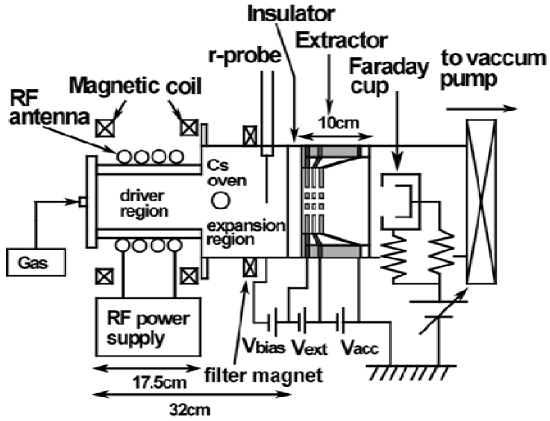

Fig. 1 Schematic of the experimental setup

can be produced with an electron density n_e of ~ 10^{19} m^{-3} in the driver region with axial magnetic field of around 20 mT. It expands into the expansion region, where a magnetic filter field (~8 mT in the center) is formed by a set of permanent magnets attached at the outside of the expansion chamber. The filter field decreases an electron temperature T_e near the plasma grid (P.G.). Plasma parameters near the extraction apertures affect the characteristics of H^- production and beam extraction. A Langmuir probe is placed near the extraction apertures and n_e and electron temperature T_e are measured.

Produced negative hydrogen ions are extracted by three electrodes consists of molybdenum plasma grid, copper extraction and acceleration grids. Each grid has 9 extraction apertures of 9 mm in diameter. The distances between the plasma grid and the extraction grid and between the extraction grid and the acceleration grid are 2 mm and 5 mm, respectively. The extraction grid has a set of permanent magnets and up to ~50 mT of magnetic field is applied for the deflection of co-extracted electron beam. The extraction voltage and acceleration voltage can be applied up to 10 kV and 15 kV, respectively. The RF source is grounded. The ion source chamber and power supplies are set on the DC high voltage stage. RF power is applied via an isolated transformer (1:1). A Faraday cup is attached downstream of the source. To evaluate the H^- beam intensity accurately, calorimetric measurements are going to be started.

A Cs oven is equipped on the expansion chamber to seed a small amount of Cs vapor. This oven and P.G. temperature are heated up by sheath heater. P.G. is covered by thin Cs layer and the work function of the grid surface decreased for the effective surface production of H^-.

3. Experimental results

RF hydrogen plasma was produced successfully at low pressure of 0.3 Pa. n_e was measured by the Langmuir probe and n_e increased with increasing RF power and axial magnetic field. The effect of magnetic filter field was confirmed. Without magnetic filter field, n_e was up to ~10^{18} m^{-3} and T_e was ~5 eV. With magnetic filter field, T_e decreased to 1 eV and n_e was about 10^{17} m^{-3}.

Produced H^- was successfully extracted at the high voltage of 15 kV without any breakdown. Extraction current (I_{ext}) and acceleration current (I_{acc}) increased with the increase of the extraction voltage (V_{ext}) and RF power. Fig. 2 shows the dependences of the extraction current and the acceleration current on the extraction voltage. With Cs vapor seeding, each current increased. In this operation P.G. was heated up about 200 degrees. With the Cs seeding, extraction current was about 400 A/m^2 and acceleration current was about 200 A/m^2 (extraction aperture area is ~6.4 x 10^{-5} m^{-2}). The e^-/H^- ratio evaluated from the ratio of (I_{ext} - I_{acc})/I_{acc} was ~1 and the ratio decreased with Cs vapor seeding.

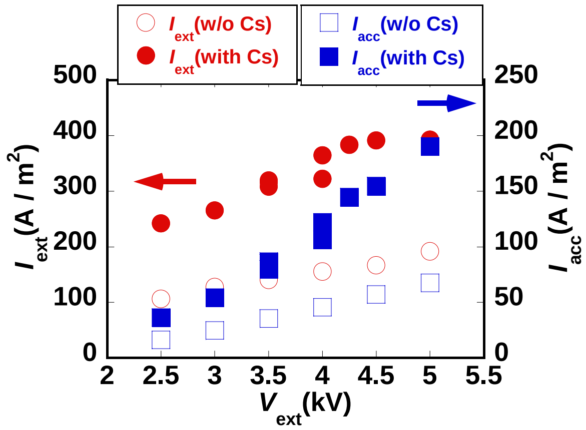

Fig. 2 Dependences of the extraction and acceleration current on the extraction voltage

4. Summary

We have fabricated a high voltage beam extraction system in a FET-based compact RF negative hydrogen ion source. High density RF plasma was successfully produced with low gas pressure. A H^- beam was extracted with the high voltage of 15 kV. Extracted H^- beam currents were measured electrically and the increase of beam currents by seeding a small amount of Cs vapor was confirmed. Evaluations of the extracted H^- beams using a calorimeter are going to be started.

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