18pE-4

Frequency dependence of plasma parameters in RF hydrogen negative ion source

高周波水素負イオン源におけるプラズマ基礎特性の周波数依存性

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Radio frequency (RF) hydrogen negative ion source is operated with frequencies of 5-7 MHz (power of 1-4 kW) and 250-450 kHz (power of ~10-20 kW). For MHz, plasma density above ~10^{17} m^{-3} is obtained downstream of the source exit for ~4 kW, while ~10 kW rf power is required to produce such hydrogen plasma for the several hundreds of kHz. Electron temperature and density are observed to decrease and increase with an increase in the rf frequency, respectively. Furthermore, negative beam extraction is performed with the acceleration energy of ~17 keV; then the similar extraction current and the larger acceleration currents are obtained for MHz operation, compared with the operation at a few hundreds of kHz.

1. Introduction

Neutral beam injection device (NBI) is a powerful and promising tool for heating a magnetically confined fusion plasma. ITER NBI requires 40 A of D^- beam accelerated to 1 MeV, and continuous operation of the ion beam for 3600 s has to be assured. For such a long-pulsed operation, it is required to develop a radio frequency (RF) hydrogen or deuterium negative ion source, which does not need any electrodes for plasma production, since electrodes in the conventional arc-filamented source are exposed to and eroded by the plasmas.

It has been proposed in our previous study that the skin depth can be increased by using a few hundreds of kHz and the rf field is efficiently generated in the plasma core, actually high density RF plasma production and the resultant increase in the negative beam extraction current have been successfully obtained [1,2]. However the effect of the driving frequency for the negative ion source performance has not been fully understood yet, while ITER has already chosen to use 1 MHz rf system [3].

In this study, the hydrogen plasma production in the range of 5 to 7 MHz is performed by using the plasma source same as in our previous study; then the results are compared with that obtained for the driving frequency of 250-450 kHz.

2. Experimental setup

Figure 1 shows the schematic of the RF negative ion source, which has been previously described [1,2]. Briefly the source consists of a 70 mm inner diameter Al_2O_3 ceramic tube (driver region) contiguously connected to a 165 mm inner diameter expansion chamber (expansion region). x, y and z axes are defined as indicated by the inset in Fig.1 and z = 0 corresponds to the upstream back plate of the source tube. A four-turn RF loop antenna is wound around the source tube and powered from a RF power amplifier via an impedance matching circuit, where the frequency is changeable from 5-7 MHz and the RF power can be increased up to ~4 kW. A uniform magnetic field is applied by two solenoids installed around the source tube and the field strength is chosen as ~10-13 mT, where the small density helicon mode jump is observed. In our previous study, it is observed that the plasma density drastically increases by applying this axial magnetic field [2].

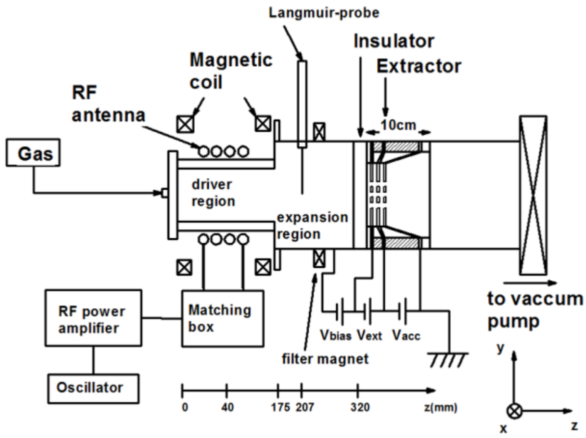

Fig.1. Schematic of the RF negative ion source.

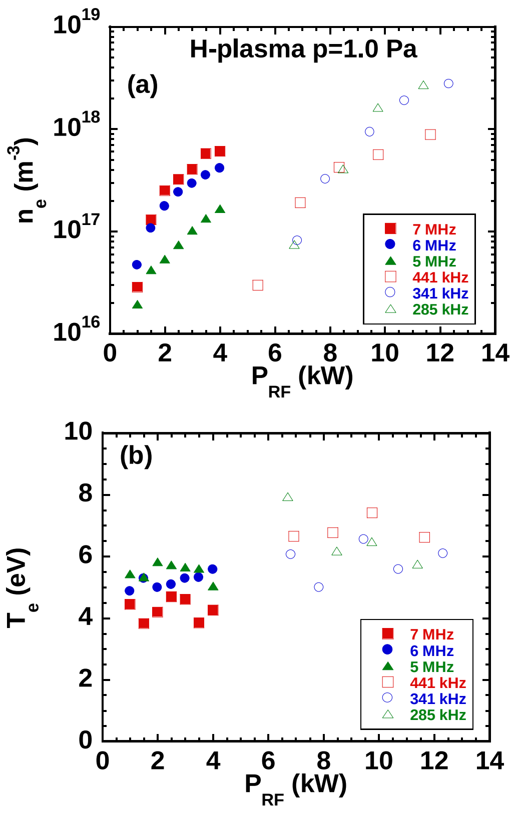

Fig.2. (a) Plasma density and (b) electron temperature as a function of the rf power.

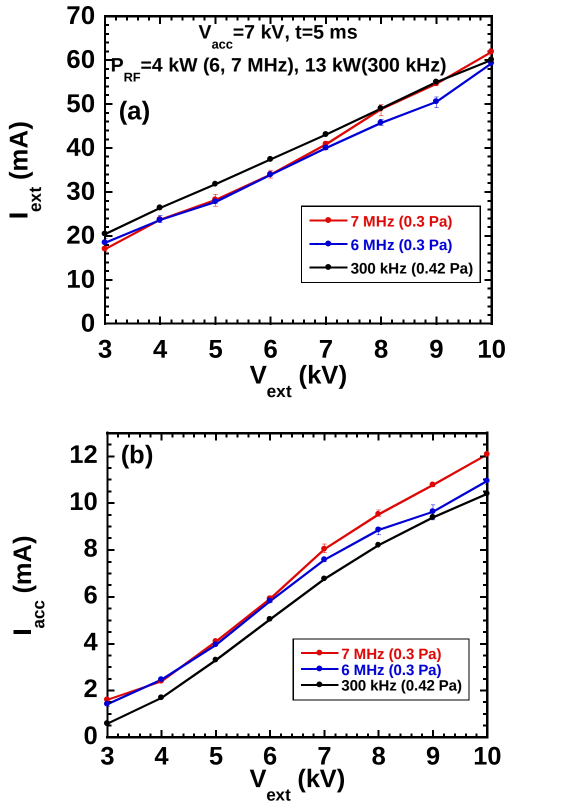

Fig.3. (a) The extraction and (b) acceleration currents as a function of the extraction voltage.

The negative ion beam is extracted by the grid system, which is composed of three grids of a plasma grid (PG), an extraction grid (EG) which holds permanent magnets to deflect the extracted electrons out of the beam, and a grounded grid. The extraction voltage is increased up to -10 kV (V_{ext}) and the acceleration voltage is maintained at -7 kV (V_{acc}) in the present study.

3. Results and discussions

3.1 *Density and temperature in expansion region*

Figure 2 shows the plasma density and electron temperature measured downstream of the driver region (207 mm) as a function of the rf power, together with the previous results using 250-450 kHz [1]. For the MHz frequency, similar plasma density can be obtained with the rf power less than that for 250-450 kHz cases and the lower electron temperature of 4-6 eV is obtained. Moreover, the electron temperature seems to decrease from ~6 to 4 eV with the increase in the frequency from 5 to 7 MHz; simultaneously the electron density increases. The low temperature does not only promote volume production of negative ions, but also prevent the destruction of negative ions due to the collision between the energetic electrons and negative ions.

3.2 *Beam extraction*

Figure 3 shows the extraction current (I_{ext}) and the acceleration current (I_{acc}) as a function of the extraction voltage (V_{ext}). Here it should be noted that I_{ext} is due to both the electrons and negative ions while I_{acc} is due to only the negative ions. It is found that the similar number of I_{ext} is obtained for MHz cases (~4 kW) compared with the 300 kHz case (~13 kW) in spite of the lower rf power. Interestingly the value of I_{acc} for MHz case is larger than that for 300 kHz case, which suggests that the density of negative ions (“not electron density”) for the MHz case is larger than that for the 300 kHz case. This is probably due to the lower electron temperature in the expansion region. The detailed performances are still under investigation.

References

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