§13. Negative Hydrogen Ion Diagnostics by the Cavity-Ring-Down Technique

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Neutral Beam Injection is one of the powerful plasma heating tools in fusion reactors. Negative hydrogen or deuterium (H^- or D^-) beams are required for NBI in the energy range of >100 keV, and negative ion sources has been successfully operated. It is known that filter magnets and Cesium (Cs) seeding system are effective for H^- production. However, the process of formation and dynamics of H^- ions in the source plasma has not been clearly understood. Recently Radio Frequency (RF) ion source has been chosen for ITER NNBI for a maintenance free operation. Characteristics of H^- ions are expected to be different from that in the conventional filament-arc ion sources. Thus, it is important to evaluate the density of H^- ions in the RF source plasma, especially near the extraction grid, and to compare with filament-arc source for understanding and optimizing the source performance. We have been developing a H^- ion source operated with a metal-oxide-semiconductor field effect transistors (MOSFET) based RF power supply at Tohoku University. The use of MOSFET enables us to use RF power with high efficiency in the frequency range of lower than 1 MHz.[1, 2] High density H^- ion production is expected in the source. One of the powerful H^- diagnostic techniques is the Cavity-Ring-Down (CRD) measurement.[3] It utilizes multi-pass laser absorption by photo-detachment process of H^- ions, and absolute line- averaged H^- density can be obtained by comparing the decay times in an empty cavity and a cavity filled with the H plasma. This study aims [1] to implement the CRD technique as a H^- diagnostics system in the FET based ion source, and [2] to clarify the characteristics of H^- ions near the plasma grid and to compare those data with that of NIFS filament-arc source obtained by the CRD technique.

The ion source consists of a driver, an expansion chamber and a set of three extraction grids. Axial magnetic field up to 17 mT can be applied at the driver. The CRD system was successfully installed. It was set at horizontally aligned diagnostic ports near the plasma grid by attaching two highly reflective mirrors (>99.999%) on each side (Fig. 1).[4] A Nd:YAG laser with 1064 nm in wavelength and ~8 ns in pulse length was used. The ring-down time in an empty cavity τ_0 was 300 μs. The lower detection limit was estimated to be ~10^{15} m^{-3}, which was small enough to measure the H^- density in our source. The electron density n_e was also measured simultaneously at the center of the optical cavity by a Langmuir probe.

The characteristics of the volume produced H^- density in the FET-based ion source were studied as functions of the basic source parameters. [1] Increase of the H^- density was observed as the electron density as a function of input RF power. The H^- density attained ~1 × 10^{16} m^{-3} and the line-averaged H^- density to the local electron density ratio was ~3% at each RF power up to 10 kW. [2] The H^- density drastically increased as a function of the externally-applied axial magnetic field in driver region. Consumed RF power and n_e also increased as the magnetic field increased, and the density ratio stayed constant. These characteristics showed a strong effect of the external magnetic field on the driver plasma production and confinement. [3] At low source pressures ~0.4 Pa, the H^- density increased (Fig. 2) while electron density stayed constant, and the density ratio reached 6%. When the source pressure was low, increase of the electron temperature was observed in the driver. This implies an increase of production of vibrationally excited hydrogen molecules that forms the H^- ions, and a decrease of dissociation of the H^- ions by collisions with hydrogen molecules.

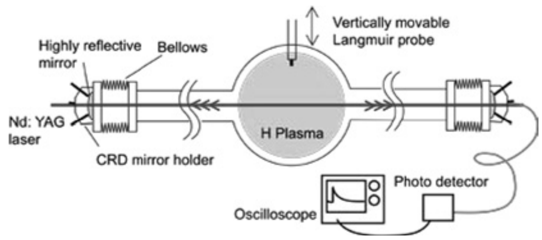

Fig. 1. Cross sectional view of the CRD system installed near the plasma grid in the FET-based ion source. The cavity length was ~1.3 m and the plasma length was ~0.1 m. Bellows were attached for mirror angle alignment.

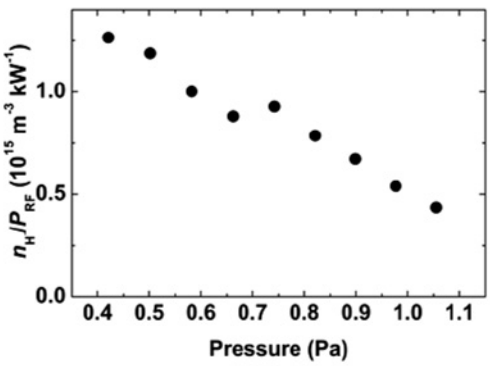

Fig. 2. Source pressure dependence of the H^- density normalized by RF power. The H^- density increased as the pressure decreased.

1) A. Ando, *et al*., Rev. Sci. Instrum **81** 02B107 (2010).
2) A. Ando, *et al*., Rev. Sci. Instrum **83** 02B122 (2012)
3) M. Burger, *et al*., Plasma Sources Sci. Technol. **18** 025004 (2009)
4) N.Tanaka, *et al*., Rev. Sci. Instrum **83** 02A731 (2012)