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Diagnostics of Negative Hydrogen Ions in a RF Ion Source by Using YAG Laser
高周波負イオン源内における水素負イオンのレーザー計測

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Negative hydrogen density measurements are required to clarify the characteristics of negative ion production. Two laser measurement techniques, one is laser photodetachment and the other is Cavity Ring Down (CRD) measurement, have been adopted in a RF FET-based ion source. The density ratio of negative hydrogen ion to the electron was successfully measured by laser photodetachment and effect of magnetic filter field on the negative hydrogen ion production was confirmed. The calculated CRD signal showed that the designed CRD system is suitable for the H^- density measurement in the RF ion source.

1. Introduction

Negative hydrogen or deuterium (H^- or D^-) ion sources are required for neutral beam injection (NBI) in next generation fusion devices. The negative ions are produced near the plasma grid (P.G.) by volume production process with the help of a magnetic filter field near the P.G. It is enhanced in surface production process on a low work function P.G. surface with cesium (Cs) seeding. The evaluation of the density of negative ions near the P.G. is one of the most important ion source plasma diagnostics. Two laser measurement methods utilizing photodetach process have been proposed for negative ion measurements. The additional electron is detached by photon irradiation with sufficient energy. Then, a negative ion density can be evaluated from (i) detached electrons detected by Langmuir probes (laser photodetachment), (ii) the absorption of the light used in the photodetachment by using sensitive absorption technique (cavity ring down (CRD) measurement).

Recently, radio frequency (RF) ion source is chosen as the reference source for ITER NBI. For high-density and effective plasma production, lower frequency of around 1 MHz is feasible because of large skin depth. We have been developing a FET (field-effect-transistor) based RF H^- ion source and successfully produced high-density plasma with lower RF frequencies (0.3-0.5 MHz) [1]. The basic characteristics of the source were presented in [2]. Efficient production of H^- ions in such ion source is expected and H^- measurements are required.

This study aims to apply the laser measurement techniques to the FET-based RF ion source and evaluate the characteristics of H^- density near the P.G.

2. Experimental apparatus

The laser measurement systems were equipped in the expansion region of the FET based H^- ion source. The expansion chamber has two laser ports and two probe ports ~40 mm upstream of the plasma grid (See Fig. 1). A set of permanent magnets that forms a magnetic filter field was attached ~20 mm upstream of the laser ports.

The principle of laser photodetachment can be found in Ref. [3]. The ratio of H^- density n_{H-} to the electron density n_e is proportional to that of photodetach signal ΔI_{es} and electron saturation current I_{es}.

$$\frac{n_{H^-}}{n_e} = \frac{\Delta I_{es}}{I_{es}} \qquad (1)$$

A Nd-YAG laser (pulse length ~8 ns, pulse energy 10-50 mJ) was injected into the expansion chamber from a fused quarts laser port. The schematics of laser photodetachment experiment are shown in Fig. 1. An L shaped Langmuir probe was installed from the bottom probe port. The photodetach signal was detected with a high pass filter. Another Langmuir probe was installed from the top probe port for electron density measurement and both probes are vertically movable.

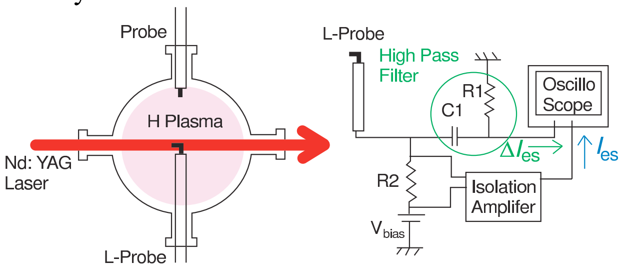

Fig.1. Schematic of laser photodetachment experiment and electrical circuit for signal detection.

A CRD measurement is an advanced laser absorption techniques [4]. Sensitive laser absorption measurement can be achieved with multi-pass configuration using an optical cavity between two highly reflective mirrors facing to each other. Line averaged absolute H^- density can be obtained by measuring a decay time of the photo signal and comparing between with and without plasma.

Nd-YAG laser of ~20 mJ in laser energy was injected into the optical cavity (mirror reflectivity R > 99.999%). The cavity length d was long enough (~1.3 m) to avoid overlap of the round-tripping laser light. The CRD signal was measured by a photo-detector set outside of the optical cavity.

3. Results and Discussions

The measured n_{H-}/n_e ratio by the laser photodetachment increased to ~10% when the magnetic filter field was adopted. Figure 2 shows the source pressure dependence of n_e and n_{H-} calculated by using eq. (1). The n_{H-} increased when the filter magnet is used showing the effect of magnetic filter field on H^- production.

In the CRD measurement, the photo signal I(t) gradually decreases according to the following equation.

$$I_{(t)} = I_0 \exp\left(-\frac{ct}{d}(1 - R + \sigma n L)\right), \qquad (2)$$

Where c is the speed of light, d is the optical cavity length, L is the length of the plasma, here defined as the width of the Gaussian distribution of plasma, σ is cross section of photodetach process at laser wave length of 1064 nm.

Figure 3 shows calculated CRD signal using eq. (2), with the following parameters: the measured plasma width L ~0.1 m, mirror reflectivity R = 99.999%, H^- density obtained from laser photodetachment $n = 10^{16}$ m^{-3}, and σ = 3.5 x 10^{-21} m^2 [5]. The decay times in the empty cavity (τ_0) and

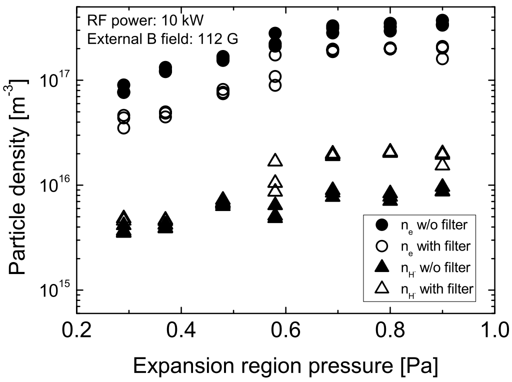

Fig.2. Expansion region pressure dependence of electron and H^- densities.

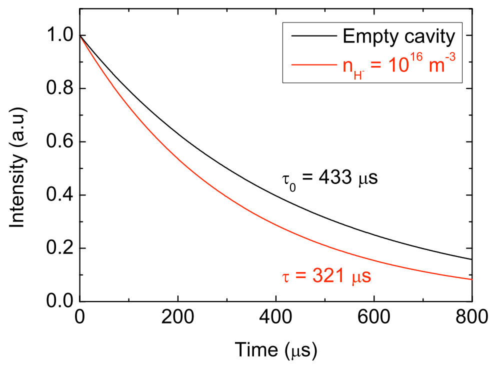

Fig.3. Calculated CRD signal.

in the cavity filled with plasma (τ) were estimated to be 433 μs and 321 μs and τ was enough smaller than τ_0. The calculation result shows that the designed CRD system is suitable for the H^- density measurement in the FET-based ion source.

4. Summary

Laser photodetachment and CRD measurement techniques were applied to a FET-based RF negative ion source. The measured density ratio was ~10%, and the effect of the magnetic filter field was confirmed. The CRD system was designed and constructed, and it was estimated that the H^- density was larger than the lowest detectable density in the designed system by calculations. The CRD measurement is going to be started.

References

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