Study of The Impurity Transport by Injecting The Gas to D-module in GAMMA 10/PDX

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Abstract. In this study, spectroscopic measurement at the plug/barrier-cell, near the midplane in GAMMA 10/PDX was carried out for the first time. From the comparison of the spectroscopic data measured in the end-cell and plug/barrier-cell, transport of impurities injected to divertor simulation module in the end-cell is investigated. It was found that Ne hardly ionized at both observation points. On the other hand, N_2 dissociated and ionized before reaches or at the plug/barrier-cell while emission spectrum derived from N_2 was dominated at the end-cell. From the comparison of the emission spectrum at the end-cell and plug/barrier-cell, it suggests that Ne was more likely to transport toward upstream region through the plasma than N_2. Time evolution of specific emission spectra, electron temperature and density suggests the reduction of the impurity transport during ECH pulse.

INTRODUCTION

The divertor magnetic field configuration has been utilized to protect the nuclear fusion reactor from high heat flow from fusion plasmas. The reduction of the heat load to the divertor plate by promoting the radiation cooling is an important subject to form the detached plasma [1-3].

GAMMA 10/PDX consists of the central-cell, anchor-cell, plug/barrier-cell and end-cell. Plasma heating devices, such as neutral beam injection (NBI), electron cyclotron resonance heating (ECRH) and ion cyclotron range of frequency (ICRF) have been installed. In GAMMA 10/PDX, ICRF wave heating is used to make high-temperature hydrogen plasma and high heat flux plasma flow is generated at the end-cell by making use of the open magnetic field. The divertor simulation experimental module (D-module) has been installed in the west end-cell. A V-shaped target plate made of tungsten is mounted in this module. The angle of V-shaped target plate can be varied from 15 to 80 degree. Several gas injection ports have been installed in D-module in order to investigate radiation cooling by injecting impurity gases. There are several spectrometers installed at the end-cell and plug/barrier-cell.

The purpose of this study is to analyze the mechanism of the impurity transport. In the experiment, various types of gases (Xe, Ne and N_2) have been injected into D-module. In this experiment, the emission spectra of impurity particles were measured by using spectrometers under several conditions, such as changing the gas throughput and gas injection timing. The effect of barrier-ECH injection on impurity transport also investigated from the comparison of the spectral measurements in the end-cell and plug/barrier-cell.

In the next section, the details of GAMMA 10/PDX and diagnostic system is described. In the subsequent section, experimental results are shown. Summary and future plan is presented in the last section.

EXPERIMENTAL DEVICE

GAMMA 10/PDX is a largest tandem mirror device. The full length of GAMMA 10/PDX is 27 m. The volume of vacuum vessel is 150 m^3. Plasma is mainly generated at the central-cell by the ICRF and gas puffing. High temperature of ion flux flows to the end-cell from the central-cell. Figure 1(a) shows the schematic view of the GAMMA 10/PDX. Plug potential is formed by plug-ECH (P-ECH) heating, and confinement capability of plug potential is depending on electron temperature. The purpose of barrier-ECH (B-ECH) heating is to trap the high temperature electron inside and prevent the low temperature electron flow upward from the end-cell. B-ECH heating forms negative potential called thermal barrier potential. B-ECH heating plays an important role to suppress cooling the electron temperature at the plug-cell. This improves the confinement performance of the plasma. Figure 1(b) shows the schematic view of D-module with gas injection. In D-module, Langmuir probes which measure the electron temperature and density and calorimeters which measure the heat flux, are installed at the corner and on the V-shape target plate. Three gas injecting systems are installed in D-module. The pipe lines are extended from gas bombes through the reservoir tank to the ports mounted near the entrance of D-module and above and under the V-shape target plate.

For diagnostic devices, two types of spectrometers, USB2000+ and SR500i, are installed at the plug/barrier-cell and end-cell. The former consists of compact type spectrometer, USB2000+, with wide band-pass (698 nm) and the latter, a high wavelength resolution of 0.018 nm FWHM at 372.26 nm, and it is also high sensitivity. In the end-cell, simultaneous measurements with SR500i and USB2000+ are performed. In the plug/barrier-cell, two same spectrometers (USB2000+) are used at the axis of Z = 862 cm (PB2) and 923 cm (PB1) as shown in Fig. 1(a). In this experiment, spectrometer measurement using at PB2 is carried out for the first time. The wavelength resolution and band-pass can be varied by changing the grating, in SR500i. In this study, USB2000+ is used for measuring wide range of wavelength with the exposure time of 5 ms. Spectrum measured by SR500i with exposure time of 40 ms, wavelength resolution is 0.031 nm FWHM @656.27 nm.

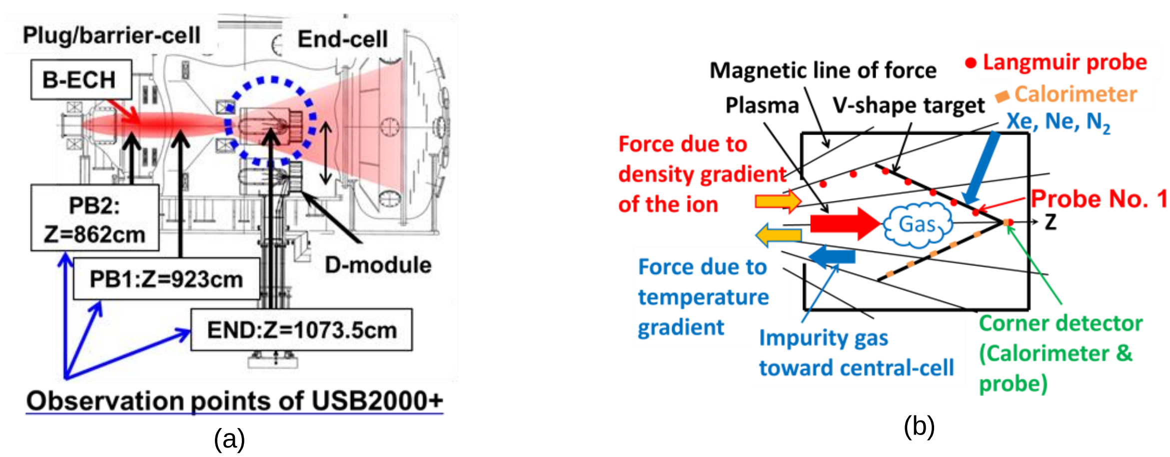

Fig. 1. (a) Schematic view of GAMMA 10/PDX west end-cell and the observation points of spectrometer at the west plug/barrier-cell and end-cell. (b) Schematic view of behavior of impurity gas in D-module.

EXPERIMENTAL RESULTS AND DISCUSSION

Behavior of Impurity Gas by Additional Heating with B-ECH

In order to investigate the impurity transport, dependence on additional heating with B-ECH is measured by using USB2000+. Gas injection was done before plasma ignition. By controlling the plenum pressure of gas reservoir, we adjusted the amount of gas injection. We defined t = 0 for the trigger timing of plasma. Hydrogen plasma is generated at t = 50 ms by gas puffing and plasma gun. Plasma is maintained up to 450 ms by the ICRF heating. Additional heating with B-ECH was applied from t = 200 ms with a pulse width of 30 ms and the power was 100 kW. We fixed the timing of gas injection from the time delay to plasma ignition. The incident time width is fixed from the open time of the valve. We also defined the plenum pressure as the pressure inside the reservoir tank. In this experiment Xe gas was injected by the following parameters (plenum pressure 2000 mbar, delay -1.2 s, width 0.5 s).

Figure 2 shows the comparison of the emission spectrum with and without B-ECH in the end-cell (a) and plug/barrier-cell (Z = 923 cm) (b). The timing of this spectrum is observed at 220-225 ms during the additional heating of B-ECH. In the end-cell, the emission of Xe II increased during the B-ECH pulse. On the other hand, at the plug/barrier-cell, same lines of Xe II decreased, while the emission spectra of H_β, C II, C III and Fe I slightly increased.

Time evolution of Xe II (492.14 nm) and C III (465.02 nm) is shown in Figs. 2(c), (d). Yellow-colored area represents the additional heating time with B-ECH. Xe II decreased drastically by additional heating with B-ECH, and then gradually increased monotonically to the end of the plasma duration. As shown in Figs. 2(d) and (e), C III and the electron density increased drastically, however in contrast with Xe II, the emission of C III quickly decreased after the end of the B-ECH pulse. The line intensity of Xe^+ $I_{Xe\ II}$ is related to Xe^+ density, electron density and electron temperature. The electron density and temperature measured in D-module did not change in both cases with and without B-ECH as shown in Fig. 2(f). From the figure, the increase of Xe II emission in D-module was not caused by the ionization of Xe gas. Accordingly, it is considered that the increase of Xe II depends on the increase of Xe^+ density. In the plug/barrier-cell, Xe II decreased and n_e increased simultaneously during the B-ECH pulse. Ionization progress to Xe^{2+} and the decrease of Xe^+ density are the possibility of this abrupt reduction. However, the rapid increase of C III was due to the increase of n_e and also presumably involved with T_e, because ECH would raise electron temperature. The electron density returns to the same value as before B-ECH. These results suggest that the gradual increase of Xe II emission spectra after B-ECH pulse was supposedly not the reversion process of ionization progress to Xe^{2+} from Xe^+. Consequently, for more probable reason, Xe^+ was forced back to the end-cell from the plug/barrier-cell during B-ECH injection. After the B-ECH pulse, Xe^+ returned to the plug/barrier-cell gradually. This implies that these exists a possibility of transport reduction toward the upstream region due to frictional force [4], which may lead to the impurity shielding induced by ECH.

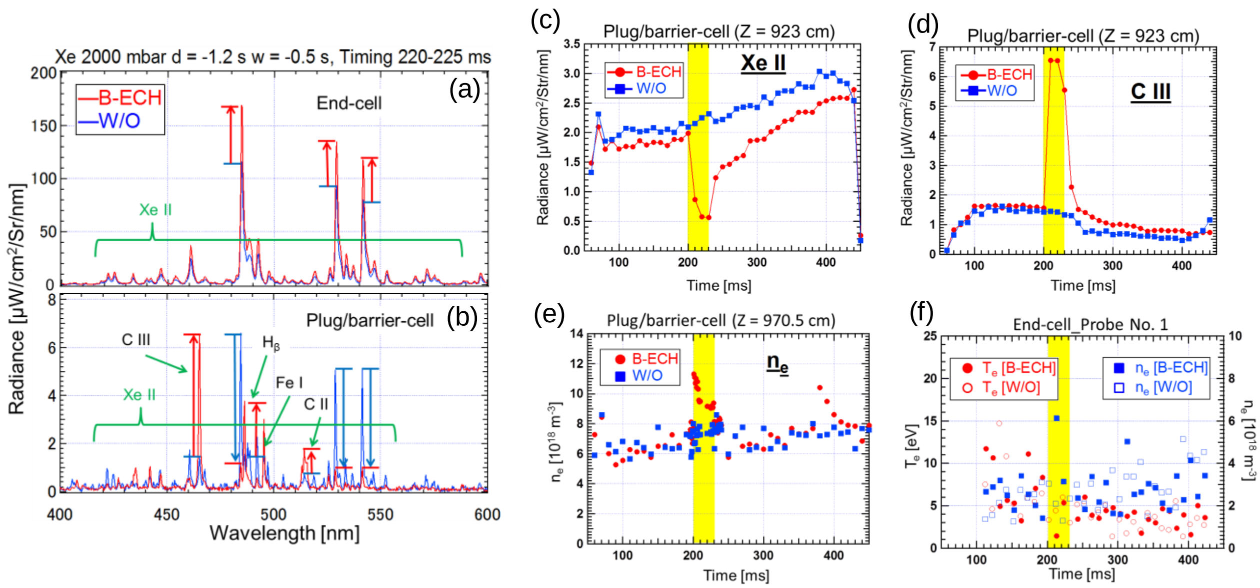

Fig. 2. The intensity of the emission line spectrum at the end-cell (a) and plug/barrier-cell (b) with and without B-ECH. Time evolution at the plug/barrier-cell of (c) Xe II (492.14 nm), (d) C III (464.74 nm) and (e) electron density. (f) Electron temperature and density in D-module measured by the probe No. 1.

Ne and N_2 Gas Injection to D-module

In this experiment, Ne and N_2 gas was injected in 1000 mbar. Each gas was injected by the following parameters (delay -0.8 s, width 1 s). Figure 3 shows the emission line spectra of Ne and N_2 at the end-cell (a) and plug/barrier-cell (Z = 862 cm) (b), respectively. The emission of Ne I was observed at the both observation points. It turned out that almost no ionized components in Ne. On the other hand, continuous spectrum of N_2 was observed at the end-cell. N_2 lines are identified as first positive system (1PS) band, second positive system (2PS) band and first negative system (1NS) band [5]. Most of N_2 were considered to be dissociated and ionized in the plug/barrier-cell or in the course of transportation to the plug/barrier-cell. Therefore, the emission of N_2 molecular line was not confirmed and some lines of N II were observed at the plug/barrier-cell in the present experiment. From the comparison of the emission spectra at the end-cell and plug/barrier-cell, it is suggested that Ne gas was likely to transport toward the upper-cell during the plasma discharge. One reason of this is considered as the interaction of Ne gas and plasma is not so strong compared with N_2. However, in the case of N_2, there are various molecular processes with plasma is considered. For instance, chemical reaction with N_2 gas or N atom, dissociation and ionization reaction. It is assumed that these interactions prevent the transport of N_2 gas and N atom toward the upstream-cell through the plasma.

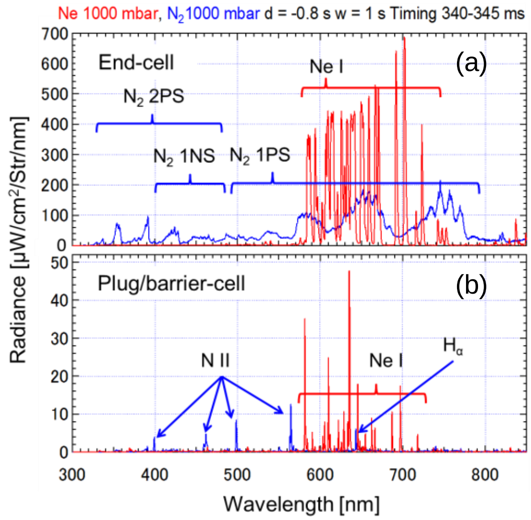

Fig. 3. The intensity of the emission line spectrum at the end-cell (a) and plug/barrier-cell (b) in Ne and N_2 gas injection experiments.

SUMMARY

The effect of additional B-ECH in the plug/barrier-cell on the impurity transport was investigated by using the spectroscopic measurement system installed in the D-module and plug/barrier-cell for the first time. The line intensity of Xe II was reduced at the plug/barrier-cell from the time of B-ECH injection. Two following reasons are conceivable, the first reason is that friction force against Xe^+ flow from the end-cell become stronger therefore the Xe^+ density was decreased in the plug/barrier-cell and for second reason is that the ionization progress of Xe^+ to Xe^{2+}. For more detailed discussion to make clear the physical mechanism of impurity shielding, measurement of electron temperature is necessary. Furthermore, reproductive experiment is necessarily to understand the phenomenon more certainly.

Simultaneous spectroscopic measurements near the midplane of the plug/barrier-cell were performed for the first time. Ne gas was not ionized in both observation points of the plug/barrier-cell and end-cell. On the other hand, various kinds of N_2 molecular spectra were observed only in the end-cell. Most of N_2 were considered to be dissociated and ionized in the plug/barrier-cell or in the course of transportation to the plug/barrier-cell. More detailed investigation is needed to clarify the behavior of N_2 gas.

ACKNOWLEDGMENTS

This study was supported by the bi-directional collaboration research program from the University of Tsukuba and National Institute for Fusion Science (NIFS12KUGM066, NIFS14KUGM086, NIFS16KUGM117). The authors thank the members of the GAMMA 10 groups for their collaboration in the experiments and their helpful discussions.

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