Ion Sensitive Probe Measurement of Divertor Simulation Plasma in GAMMA 10/PDX

N. Ezumi [1, a)], K. Nojiri [1], A. Terakado [1], K. Ichimura [1], M. Sakamoto [1] and Y. Nakashima [1]

[1] *Plasma Research Center, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8577, Japan*

[a)] Corresponding author: ezumi@prc.tsukuba.ac.jp

Abstract. An ion sensitive probe (ISP) has been installed in the divertor simulation module of the largest tandem mirror plasma device GAMMA 10/PDX in order to evaluate the property of the high temperature end loss plasmas. The ISP has the capability to evaluate ion temperature (T_i), electron temperature (T_e), electron density and plasma space potential, simultaneously. We have tested the ISP measurement for several discharge and neutral gas pressure conditions. T_i evaluated by using an ion collector of the ISP shows ~ 6 eV which corresponds to the perpendicular component of T_i in principle. T_e evaluated by the current-voltage characteristics of an electron guard electrode of the ISP shows ~ 4 eV which is lower than T_e obtained by Langmuir probes upstream and downstream of the ISP. These results indicate the existence of anisotropic ion and electron temperatures in the D-module.

INTRODUCTION

Ion sensitive probe (ISP) is an electrical probe used for measuring ion temperature (T_i) in magnetized plasmas [1]. Simultaneously, electron temperature (T_e) and plasma space potential (V_s) are also available. Recently, the ISP was installed in the divertor simulation module (D-module) of the largest tandem mirror plasma device GAMMA 10/PDX in order to evaluate the property of the high temperature end loss plasmas which are equivalent of the edge and divertor plasmas in tokamaks and helical devices. These measurements are expected to contribute to realizing the important physics in handling extremely high heat and/or particle load to the plasma facing components of magnetic fusion devices. Since the ISP measurement is based on the difference of the Larmor radius between ions and electrons, the evaluated T_i contains mainly perpendicular component of the temperature ($T_{i\perp}$) [2]. On the other hand, evaluation of parallel component of the ion temperature ($T_{i//}$) is attempted by using ion saturation current measured by ordinary Langmuir probes and an outer electrode of the ISP, which works like a Langmuir probe, since the sound speed has the dependence of the parallel T_i as well as T_e in the case of $T_i >> T_e$ [3, 4]. In this paper, we show typical results of the ISP measurement and discuss validity of the results.

EXPERIMENTAL SETUP

Divertor simulation module in the tandem mirror device GAMMA 10/PDX

ISP measurements have been done in the largest tandem mirror device GAMMA 10/PDX, which has large vacuum chamber with 27 m in length and with maximum magnetic field B ~ 3 T. The device can generate high temperature confinement plasma in a central-cell region, utilizing ICRF and ECH heating systems. Typical plasma density, ion temperature and electron temperature at the central cell are ~ 10^{18} m^{-3}, 10 keV and 100 eV, respectively. The plasma duration is typically 200 or 400 msec. The confined plasma flows into open field regions at end-cell regions on both side of the device through magnetic mirrors. The plasma in the end-cells, so called "end-loss plasma", has still kept high ion temperature of several hundred eV. We have utilized the end-loss plasma for investigating divertor plasma because the end-loss plasma is equivalent to ITER SOL and divertor plasma conditions especially high T_i and B.

In order to simulate high recycling condition at divertor region, the D-module has been installed in the end-cell region [5,6]. The D-module has a metal box with the dimension of 50 cm x 50 cm x 70 cm in width, height and length, respectively. The diameter of plasma is about 10 cm at the inlet aperture and 30 cm at V-shaped target plate. B is also changing along the open magnetic field structure, B = 1.5 T at the inlet and 0.15 T at a corner of the target plate. The typical plasma parameters in the module has density $10^{17} \sim 10^{18}$ m^{-3}, $T_e \sim$ several tens eV for only RF heating and $T_i \sim$ a few hundred eV in low neutral pressure condition.

Figure 1 shows schematics of the ISP installed in the D-module of GAMMA10/PDX. The installed ISP consists of two electrodes that an ion collector (P) and an electron guard electrode (G). The both electrodes are biased at same voltage by using a bipolar power supply. The ion collector collects ions only on the probe bias voltage near the V_s. The guard electrode works as a fence to prevent electrons flowing into the ion collector. These behaviors are based on the difference of the Larmor radius between ions and electrons in a magnetic field. The P and G-electrodes are made from molybdenum. These electrodes are insulated by boron-nitride each other. The distance between the top surface of the ion collector and the upper end of the G-electrode is set to 0.5 mm according to the Katsumata's theory [1], where T_e and B were assumed to several tens eV and 0.68 T, respectively. LPs are made from tungsten. The shape of electrodes is cylindrical. Almost same voltage is applied for the both electrodes using a bipolar power supply. Note that the P-electrode usually has constant negative bias voltage of a few V in order to avoid unexpected electron influx. The voltages for the both electrodes are scanned with 50 Hz in same phase for obtaining current-voltage (I-V) characteristics during the discharge. The probe currents for P and G electrodes are measured with shunt resistors. The voltage signals are recorded by using digitizers with 1MSamples/s sampling rate.

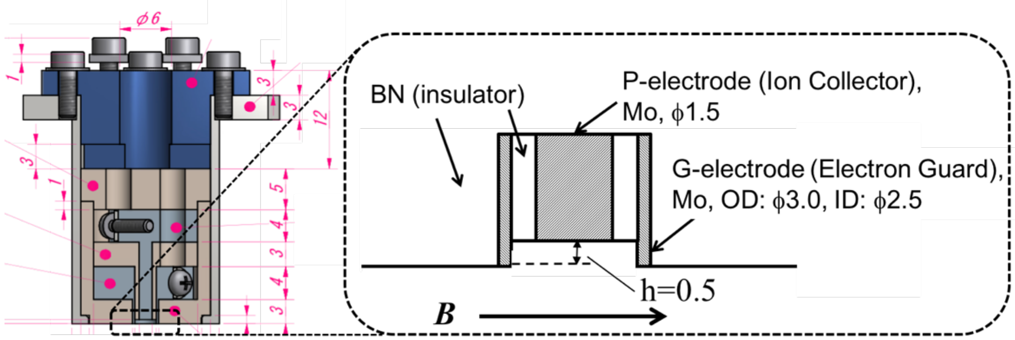

FIGURE 1. Schematics of the ISP

Figure 2 shows the location of probe electrodes in the D-module. Langmuir probe array system on the V-shaped target and two Langmuir probes (LPs) between the inlet and the target have been installed. ISP is placed on Z=10.505m where is between the two LPs along the same magnetic flux tube.

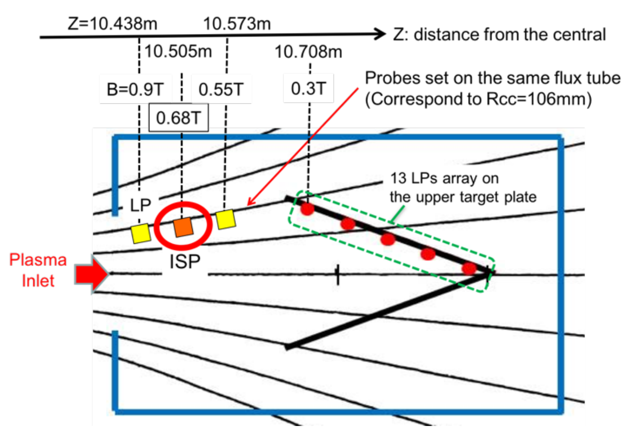

FIGURE 2. Probes layout in the divertor simulation module. The ISP is placed at Z = 10.505 m.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 shows *I-V* characteristics of the ISP obtained at t ~ 114 msec after main trigger of the shot #232994. Probe current in a) shows only ion current flow into the ion collector, because ion separation is well operated on the ion collector in this case. The current is exponentially decreased in positive bias region over V_s. When we assume the ion has Maxwell velocity distribution, the slope indicates T_i ~ 6.5 eV. On the other hand, as shown in b), *I-V* curve on the guard ISP looks like ordinal Langmuir probe characteristics. The slope of the *I-V* curve shows T_e ~ 4.5 eV assuming Maxwell distribution for electron, too. V_s is also estimated by the graph as ~ 18 V.

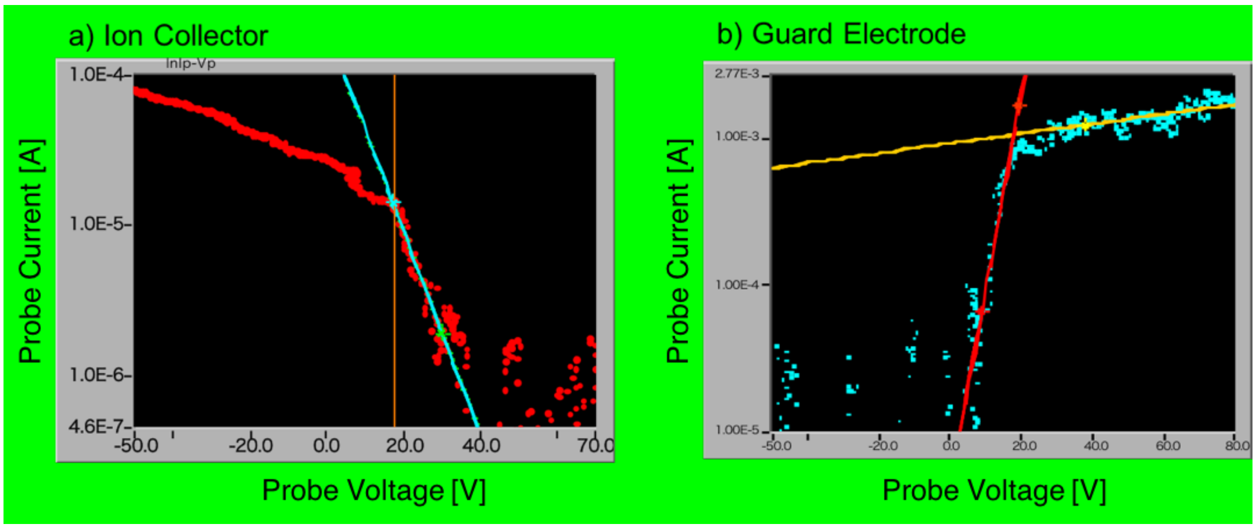

FIGURE 3. Typical ISP current-voltage characteristics obtained by a) the ion collector and b) the electron guard electrode.

The conventional T_i evaluation method which uses exponential fitting for current-voltage characteristics obtained by P-electrode of the ISP, mostly shows perpendicular component of T_i because of the geometrical structure of the electrodes [2]. The other way, which is attempt to evaluate parallel component of T_i , is utilizing dependence of ion saturation current on T_i [3]. In the case of $T_i >> T_e$ such as our experimental condition, using ion saturation current I_{is} and electron current I_{e0} at plasma space potential V_s, parallel component of T_i is evaluated by following equation [4];

$$kT_i = \frac{1}{\gamma}\left\{\frac{1}{2\pi\cdot 0.6^2}\frac{m_i}{m_e}\left(\frac{I_{is}}{I_{e0}}\right)^2\left(\frac{S_e}{S_i}\right)^2 - 1\right\}kT_e \qquad (1)$$

where e is elementary charge, k is Boltzmann constant, m_i is ion mass, γ is heat capacity ration, S_i is effective collection area for ion, m_e is electron mass and S_e is effective collection area for electron. The attempt to analyse parallel T_i using eq. (1) for the G-electrode of ISP shows several tens eV. Here, γ is assumed to be 3. The parallel T_i estimated by ion saturation current on the ISP shows almost ten times higher than the perpendicular one. This result indicates the existence of strong anisotropy for the T_i. These are reasonable results because the strong T_i anisotropy due to the mirror configuration of GAMMA10/PDX [4].

Figure 4 shows the change of T_e and n_e along the magnetic field in the D-module. The compering probes are placed on the same magnetic flux tube. The radial positions of these probes correspond to 106 mm in radius of the central-cell. Increase of n_e and decrease of T_e along B are observed. The tendency can be explained by ionization due to high neutral pressure ~ 2 Pa in the D-module. Though n_e has been gradually changing, T_e profile differs from n_e. T_e measured by the G-electrode of ISP located at Z = 10.5 m shows low T_e comparing with other LPs. The difference suggests that perpendicular component of T_e is measured because the G-electrode of ISP is flash-mounted in the boron-nitride shielding sleeve as shown in Fig. 1. We considered that most electrons which reach the G-electrode have been moved perpendicular to the magnetic field line due to small gyro-radius of electron.

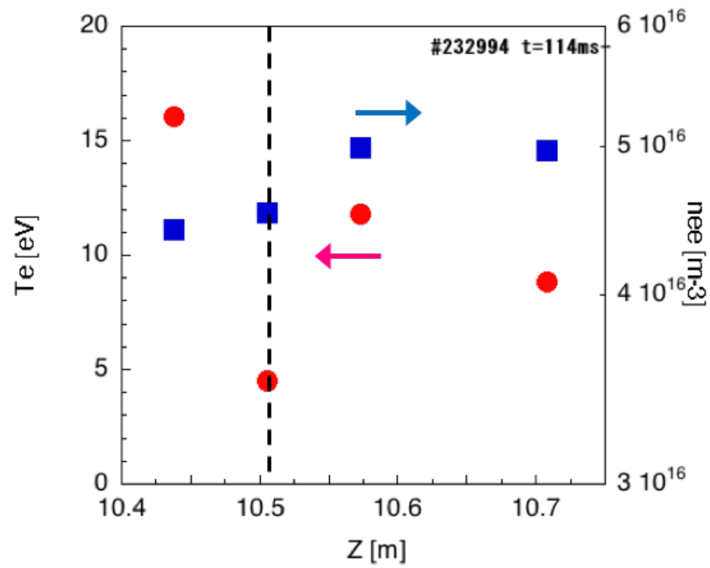

FIGURE 4. Electron temperature and electron density at several positions on Z-axis. The position indicated dotted line corresponds the place of the ISP. The other positions have ordinal Langmuir probes.

SUMMARY

Typical results of ISP measurements in the D-module of the large tandem mirror device GAMMA 10/PDX have been shown. I-V curves of the ISP indicate ion separation on the ion collector and work well for estimating T_i. Utilizing ion saturation current for evaluating ion temperature, the existence of anisotropic ion temperatures in the D-module has been indicated. Comparing T_e along Z-direction, electron also has anisotropy of the temperature. For more detail measurement of T_i, especially parallel component, we are preparing for laser induced fluorescence measurement using a tunable laser.

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