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# Measurement of ion temperature using Langmuir probes in divertor simulation experiments on GAMMA 10/PDX

GAMMA 10/PDX ダイバータ模擬実験における
静電プローブを用いたイオン温度計測

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One of the features of GAMMA 10/PDX is high ion temperature. We have tried to evaluate ion temperature of the divertor simulation plasma using a Langmuir probe. The ion temperature of a typical plasma, which is produced by ICRF heating, can successfully be obtained to be in the range of 100 - 250 eV. It agrees well with a result that is obtained by the end loss ion energy analyzer.

## 1. INTRODUCTION

The divertor magnetic configuration is important to reduce heat load on the first wall [1]. It is necessary to understand plasma behavior in the divertor region. Ion temperature as well as electron temperature is important information to study divertor plasma behavior, for example, the divertor detachment [2-4]. So far, ion temperature has been measured using electrostatic probes such as ion sensitive probe (ISP) [2,4,5], asymmetric double probe [6] as well as optical methods such as Doppler broadening.

In GAMMA 10/PDX, the divertor simulation experiments have been carried out using a divertor simulation experimental module (D-module), which is installed in the west-end region [7,8]. Langmuir probes are installed on the V-shaped target in the D-module. One of the features of GAMMA 10/PDX is high ion temperature (a few hundreds eV for the end loss plasma, which is close to the SOL temperature in ITER) [9]. In this study, we have tried to evaluate ion temperature of the divertor simulation plasma from V-I characteristic of the Langmuir probe making best use of the feature of GAMMA 10/PDX.

## 2. Evaluation method of ion temperature

The ion and electron saturation currents are written by the following equation:

$$I_{\mathrm{is}} = 0.6 e S n_{\mathrm{e}} \{k(T_{\mathrm{e}} + \gamma T_{\mathrm{i}})/m_{\mathrm{i}}\}^{1/2}, \qquad (1)$$

$$I_{es} = e S n_e (k T_e / 2\pi m_e)^{1/2}, \qquad (2)$$

where $S$ is the effective probe surface area, $m_i$ is mass of the ion, $\gamma$ is an index depending on thermodynamic property of ions [10], where we assume $\gamma = 1$. The electron temperature $(T_e)$ can be evaluated from the slope of the logarithmic plot of the electron current $(I_e)$ versus probe voltage. The electron density $(n_{\mathrm{e}})$ was evaluated from electron saturation current $(I_{es})$ and $T_{\mathrm{e}}$. Finally, the ion temperature $(T_{\mathrm{i}})$ can be evaluated by using the following equation:

$$T_i = \left\{ \frac{m_i}{2\pi m_e} \left( \frac{I_{is}}{0.6 I_{es}} \right)^2 - 1 \right\} T_e \qquad (3)$$

In almost all linear plasma devices, the ion temperature cannot be evaluated by using a Langmuir probe, since it is rather low. In GAMMA 10/PDX, however, the ion temperature can be obtained because it is high.

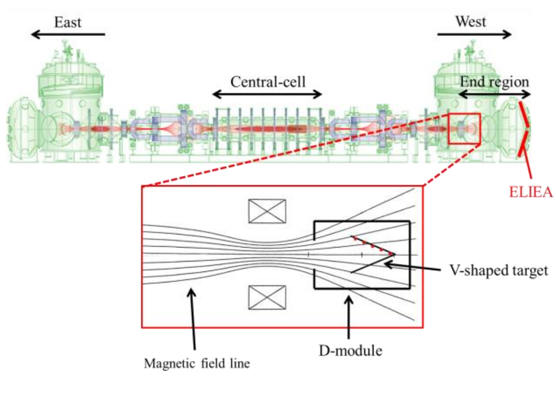


Fig.1 Schematic views of GAMMA 10/PDX and the D-module

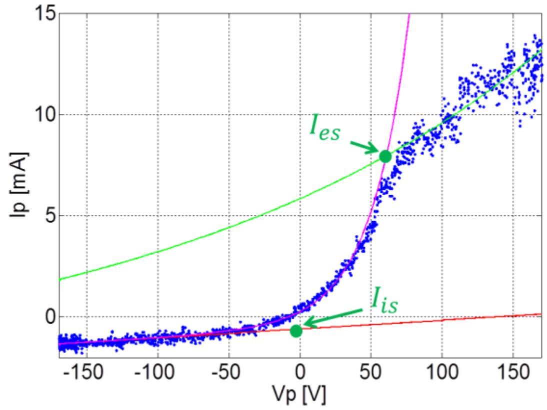


Fig.2 Probe current as a function of the probe voltage of a Langmuir probe on the V-shaped target. The probe was installed at 175 mm from the corner of V-shaped target.

## 3. Experimental Setup

GAMMA 10/PDX is a tandem mirror device with minimum-B anchor. It consists of a central cell, anchor cells, plug/barrier cells and end regions. In the central cell, main plasma is produced and heated by ion cyclotron range of frequency (ICRF) waves together with gas puffing.

The D-module is installed in the west-end region. A V-shaped target is installed in the D-module. An open angle can be changed from 15 to 80 degrees. In this study, the open angle of the V-shaped target was 45 degrees. The D-module can be moved up and down. In the divertor simulation experiments, the D-module is set at the upper position. In the other experiments, it is set at the bottom of the end region.

Thirteen Langmuir probes are installed on the upper target. The sine-wave sweep voltages from -170 V to 170 V at 50 Hz were applied to the probe.

Ion temperature of the end loss plasma was also evaluated by using an end loss ion energy analyzer (ELIEA), which is installed at the west end and can measure the energy distribution of the end loss ion. Magnetic field at the Langmuir probes and the ELIEA are 0.15-0.3 T and 0.01 T, respectively.

## 4. Experimental results

In this study, the main plasma was produced by ICRF waves of which power was 270 kW. The electron temperature and density of the central cell plasma were $35 \pm 5$ eV and $\sim 2.0 \times 10^{18}$ m$^{-3}$, respectively. The end loss plasma was exposed to the V-shaped target in the D-module.

Figure 2 shows the probe current as a function of the probe voltage. The ion saturation current is $0.80 \pm 0.05$ mA and the electron saturation current is $8.2 \pm 0.5$ mA. The electron temperature and density are evaluated to be $30 \pm 2$ eV and $(2.5 \pm 0.2) \times 10^{16}$ m$^{-3}$, respectively. From these values and eq (3), the ion temperature can be obtained to be $210 \pm 40$ eV. Error of $I_{is}$, $I_{es}$ and $T_e$ are estimated from uncertainty of curve fitting of the V-I characteristic. Error of $T_i$ and $n_e$ are estimated from propagation of the errors.

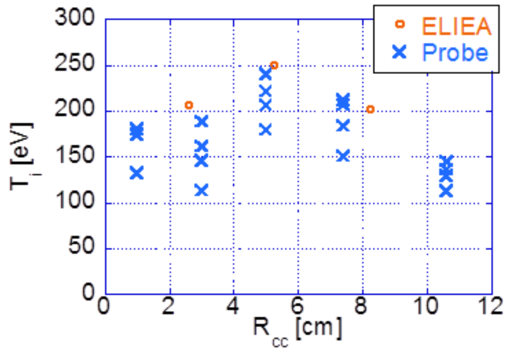


Fig.3 The distribution of ion temperature as a function of a radius projected to the central-cell.

The measurement with the ELIEA was carried out when the D-module was set at the bottom of the end region. The ion temperature was evaluated from the slope of the energy spectrum and it was in the range of 200-250 eV. The uncertainty of the ion temperature is now under consideration.

Figure 3 shows a spatial distribution of the ion temperature as a function of $R_{cc}$, where $R_{cc}$ is a radius projected along the magnetic field line from the end region to the central-cell. The distribution of the ion temperature measured by Langmuir probes agreed well with that of ELIEA. We are considering the uncertainty of the ion temperature.

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