

Application of Ion Sensitive Probe to High Density Plasmas in Magnum-PSI

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Feasibility of an ion sensitive probe was evaluated in high electron density ($> 5 \times 10^{19} \text{ m}^{-3}$) helium plasmas produced in the Magnum-PSI device. The ion sensitive probe showed that the ion temperature was $\sim 1 \text{ eV}$ and almost equal to the electron temperature. Increasing the neutral pressure to efficiently lead to the electron-ion recombination processes, the electron currents were collected at the ion collector. A secondary electron emission in the guard electrode might have an effect on the ion current.

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Plasma detachment is realized by means of volumetric recombination processes in front of the divertor targets in magnetically confined fusion devices. Electron-ion recombination (EIR) processes dominate when the electron temperature, T_e , is less than 1 eV, and the rate coefficients of molecular activated recombination (MAR) processes have a peak at $T_e \sim 1\text{--}2 \text{ eV}$ [1]. Contribution of ion temperature, T_i , is considerable on the cooling process of electrons on such a low temperature plasma. This is because the electron-neutral interactions such as electron impact ionization and excitation are less dominant than T_e - T_i relaxation process when $T_e < 5 \text{ eV}$. The insufficient collision between ions and neutral particles discourages a reduction in T_i . As a result, T_i determines a lower limit of T_e .

Energy balance among electron, ion and neutral particles can be investigated in detail by utilizing the steady state plasma generated in linear plasma devices. The ion temperature was measured with an ion sensitive probe (ISP) [2] in some linear plasma devices [3,4]. In this Rapid Communication, the purpose is to investigate feasibility of an ISP application to high electron density, n_e , and high neutral pressure, P_n , plasma in Magnum-PSI [5], where the parameters are relevant to divertor region in ITER.

Magnum-PSI generated a steady-state He plasma. In order to measure T_i in the case that EIR processes are dominant, plasma-neutral interactions were enhanced by means of additional He puffing in target chamber, hence increasing the He neutral pressure, P_n . The magnetic field of 0.3 T, which was produced by superconducting coils,

provided confinement of the plasma. Because the ion cyclotron frequency was greater than the ion-neutral collision frequency, we could assume the magnetized plasma. The plasma column was terminated with a target plate. It is expected that T_i and T_e are in the range of 0.5–2 eV in front of the target plate. Under these conditions, the ion and electron Larmor radii are 0.8–1.5 mm and 9–18 μm , respectively. The Larmor radius is an important parameter in the application of the ISP to magnetized plasma. Figure 1 (a) shows the schematic of the ISP. The ISP consists of a rod-shaped ion collector and a cylindrical guard electrode surrounding the ion collector. The top surface of the ion collector is located deeply from that of the guard electrode to avoid inflow of electrons and to collect only ions at the ion collector. In the present study, the distance between the top surfaces of two electrodes (denoted by h in Fig. 1 (a)) was set to be 0.5 mm. The ISP was vertically inserted into the plasma column and measurements were performed at a radial position, r , of 7 mm and with the distance of 80 mm from the target. The diameters of the ion collector and guard electrode were, respectively, 0.5 and 1.5 mm, which were selected not to disturb the plasma column with the diameter of 20 mm.

Figures 1 (b)–(d) show the current-voltage (I - V) characteristics of the ion collector and the guard electrode in the ISP. Here, I_p and I_g denote, respectively, the currents into the ion collector and the guard electrode, which are at the voltages of V_p and V_g , respectively; V_p was negatively higher than V_g by 1.5 V to avoid an electron current into the ion collector. Figure 1 (b) shows the I - V characteristics

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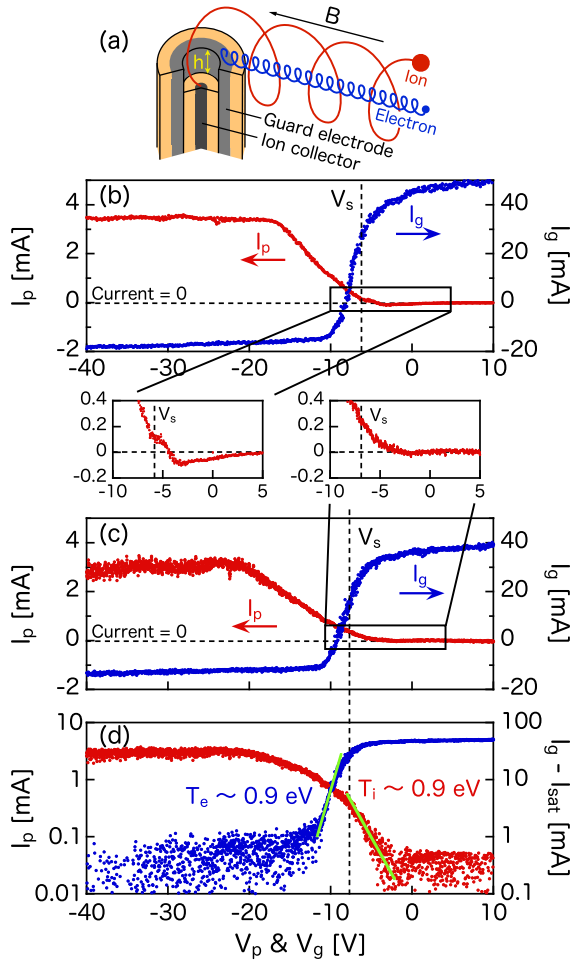


Fig. 1 (a) Schematic of ISP. (b) I - V characteristics of the ISP ($I_d = 160$ A, and $P_n \sim 1.3$ Pa). (c) Linear and (d) logarithmic plots of I_p and I_g ($I_d = 140$ A and $P_n \sim 0.3$ Pa).

when the discharge current, I_d , of 160 A and $P_n \sim 1.3$ Pa. When $V_p \sim$ the space potential, V_s , electron currents were collected in the I_p curve, meaning that the separate collection of ions in the ion collector failed. In the experiments performed in PSI-2 [3], similar unanticipated negative currents were found when $V_p \geq V_g$. The problem was caused by the electrons moving by $\mathbf{E} \times \mathbf{B}$ drift along the equipotential surface that intersects with the ion collector [6]. However, this was not the case in the present study, because $V_p < V_g$ was ensured.

A reason for making I_p negative could be the influence of secondary electron emission in the guard electrode. The Refs. [7, 8] explained that the second electron current from the probe surface was induced by metastable He flux. Some of the secondary emitted electrons from the guard electrode can reach the ion collector, leading to the negative current observed in I_p . The second electron current was small and not seen in I_g curve, whereas the impact was not negligible regarding I_p because of the small ion current. Although the present pressure was much lower than the cases in [7, 8], there should be many metastable

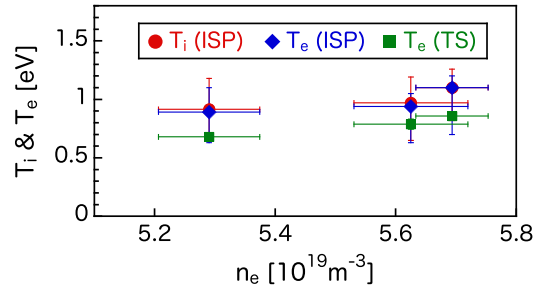


Fig. 2 Scatter plots of T_e and T_i vs. n_e under three different discharge conditions. ($P_n \sim 0.3$ Pa).

atoms in the present experiments, as well, because the metastable states can be produced by EIR processes at the present T_e [9]. The effect of metastable atoms on the ISP measurement should be investigated by comparative experiments with different source gas which does not include metastable.

Figures 1 (c)-(d) show typical I - V characteristics of the ISP when T_i can be analyzed. The I - V characteristics were obtained at I_d of 140 A and P_n of 0.3 Pa. The inflow of electrons into the ion collector was not observed when V_p was greater than V_s in the I_p curve, meaning that only ions were successfully collected separately from electrons. The logarithmic plots of I_p and I_g after the subtraction of the ion saturation current, I_{sat} , give us $T_i \sim T_e \sim 0.9$ eV at the same time. Here, the fitting ranges for T_i and T_e were selected when V_p and V_g were, respectively, higher and lower than V_s and when I_p and I_g showed exponential decay.

Figure 2 shows n_e dependences of T_i and T_e . In order to observe n_e dependence, I_d was varied from 140 to 160 A at the P_n of 0.3 Pa. Thomson scattering (TS) measurement at the ISP position was performed to obtain n_e and T_e . The measured T_e by TS measurement is also shown in Fig. 2. A systematic discrepancy between ISP and TS were found. The validation of ISP diagnostics in recombining plasma is necessary in detail by a quantitative comparison with the collective TS [10] and the TS in the future. Slight increases in T_e and T_i with n_e were due to the increase in discharge power. Thermalization between ions and electrons can easily occur, because the density is high in the Magnum-PSI device. Roughly, the estimated T_i - T_e relaxation time was of the order of μ s, whereas typical ion resident time estimated with the plasma length and ion sound velocity was of the order of 100 μ s. Therefore, thermal equilibrium between ions and electrons can be assumed at the target region.

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