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Experimental investigation of free and bounded presheaths in weakly magnetized plasmas

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ABSTRACT

Transports of plasmas in the edge of fusion devices have similarities in terms of formation of a free presheath and unclear explanation on the transport process relating the diffusion coefficient ($D_\perp$) to characteristic length of perturbing for flux tube (L_c). $D_\perp$ and L_c are investigated by generating perturbations in various free presheaths due to a perturbing object located at the axial center of a linear plasma device, called DiPS (Divertor Plasma Simulator). Free presheaths are generated due to a tungsten perturbing object by changing the magnetic flux density. Bounded presheaths are also formed due to a limiting structure of a magnetic nozzle and due to the given geometry of DiPS. In terms of plasma discharge currents, radial plasma profiles were measured by using a fast scanning probe system. $D_\perp$ and L_c within the free presheath regions were calculated by using the measured plasma parameters and compared with those of bounded presheaths near the chamber walls. Decay length of plasma density was introduced to calculation of $D_\perp$. To calculate the perturbation length (L) of free presheaths, a theoretical scale factor K was introduced as $L = KL_c$ using a fluid model. Normalized factor $\delta = D_\perp/D_B$, where $D_B =$ Bohm diffusion coefficient, were obtained as 8 at free presheaths and 11 at bounded presheaths.

1. Introduction

Problem of plasma surface interaction and sheath is one of the oldest problems, yet is not fully understood. It is not only important for nearly all applications where a plasma is confined to a finite volume, but also relevant in plasma technology including fusion research with undiminished or even growing interest [1–4]. The performance of core plasma is usually affected by edge scrape-off layer (SOL) plasmas, and the understanding of mutual interactions among the core, edge plasmas and the surface including the flow and transport has been one of the key issues in fusion research [5–8]. All of these problem are linked to momentum or energy transports of plasma in the SOL and the transport processes of plasma at these boundary conditions are complex and usually require extensive numerical simulation or experimental investigation to check the relative importance of the various parameters and desired optimal conditions for enhanced operation [8,9]. Generally, the plasma density at the center of bulk plasma is higher than the sheath or near the walls, which leads to particle diffusion from the plasma center to walls. However, when a perturbing object, such as an electric probe is inserted into the SOL, it makes the diffusion phenomena somewhat different from general conditions of plasma and adds complication for the interpretation of electric probes or the other plasma diagnostics. When the magnetic field is strong enough that the ion gyro-radius is substantially smaller than the probing object, ion collection across the field is diffusive even if the parallel flow is dominated by inertial effects [10,11]. Consequently, the investigation of diffusion coefficient ($D_\perp$) and characteristic length of perturbing for flux tube (L_c) are to be simplified and understood as one-dimensional phenomena of plasma boundary in the magnetized plasma [7–13].

In this paper, as a simulated experiment of fusion plasma edge transport by a linear plasma device, called DiPS (Divertor Plasma Simulator) [14], $D_\perp$ and L_c have been investigated when the free and bounded presheaths are produced in weakly magnetized plasma. By inserting a tungsten perturbing object (TPO) in the magnetized plasma stream, we generate a free presheath [8,10,11,15,16] along with a bounded presheath near the wall. Both presheaths are geometrically described in the section of experimental setup. In

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terms of plasma discharge currents, radial plasma profiles were measured and investigated by using fast scanning probes system (FSP) with single probe (SP) and triple probe (TP). Then, the $D_{\perp}$ at free and bounded presheath regions were analysed in terms of plasma density and electron temperature/magnetic flux density, compared with Bohm diffusion coefficient (D_B). Finally, the theoretical value $K(\equiv L/L_c)$ upon a fluid model was introduced for considering transport parameters to analyse the perturbation presheath length (L) at a free presheath.

2. Experimental setup

Divertor Plasma Simulater were developed as a linear plasma device for application of probe technique to various areas, such as divertor plasma simulation in fusion devices, to understand a magnetized presheath region of a simulated tokamak plasma wall interaction zone [14]. The mild toroidicity could be compensated by the control of the discharge current ($I_{dis.}$) to change poloidal magnetic fields (B_p) with axial magnetic fields (B_z). For example, considering a normal operation condition for DiPS where electron temperature (T_e) ~ 1–20 eV, plasma density (n_e) ~ 10^{12} cm^{-3}, B_z ~ 0.1–1 kG, r ~ 1 cm, Plasma current (I_p) and B_p ($B_p = \mu_0 I_p/2\pi r$, where μ_0 is permeability of free space) are 1–100 A and B_p ~ 0.1–10 G, respectively. B_P/B_z ~0.01–0.1 is to be achieved, which leads to $q = 3 - 30$ with respect ratio $R/a \approx$ 3, and indicates typical validity of an experimental approach to investigate phenomena in the fusion plasma by using a linear plasma device. Schematic diagram of DiPS and the experiment set-up to analyse $D_{\perp}$ and L_c at a free presheath in weakly magnetized plasma is shown in Fig. 1. DiPS has a magnetic nozzle for the formation of a magnetic hill and geometrical production of a bounded presheath, which experimentally induces the more similar environment with the magnetized plasma at SOL region in the fusion device. Besides, this magnetic nozzle with $B_N = 3.5$ kG could simulate the edge localized mode (ELM) phenomena by changing its ratio to that (B_0) of test region, i.e., $1 \le B_N/B_0 \le 30$.

Schematic views described for FSP and TPO systems are shown in Fig. 2. TPO, which is located at the axial center of plasma stream generated from the LaB_6 DC plasma source in DiPS, produces a free presheath in the magnetized plasma. Dimensions of TPO were 3 cm length (z-axis) and 1.5 cm diameter (r-axis). To prevent the melting of TPO due to high heat fluxes transferred from plasma, cooling water is supplied to keep temperature far lower than tungsten melting point. Two electric probes, as a combination of SP and TP, were located at 16 cm front and 16 cm back side of TPO, respectively. Electric probes were installed on FSP, which were able to scan the radial plasma profiles with speed of 1 m/s. Schematic diagram of data collection system and raw data obtained from a FSP performance test are shwon in Fig. 3. DC 100 V bias was applied to probe tips for measurement of probe signals such as ion saturation currents (I_{sat}) and potentials (V_1 and V_2) as shown in an electric circuit of Fig. 3 (b). Radial scanning distance was converted from bias signals measured by using linear position transducer. To analysis electron temperature and plasma density, $T_e = e(V_1 - V_2)/0.693$ and $n_e = I_{sat}/\alpha e A_s\sqrt{kT_e/m_i}$ were calculated where e, α, A_s and k are electron charge, coefficient for the collective ion saturation current, sheath area and Boltzmann constant, respectively. $A_s = A_p = \pi a_p^2$ (probe tip area) is assumed and radius

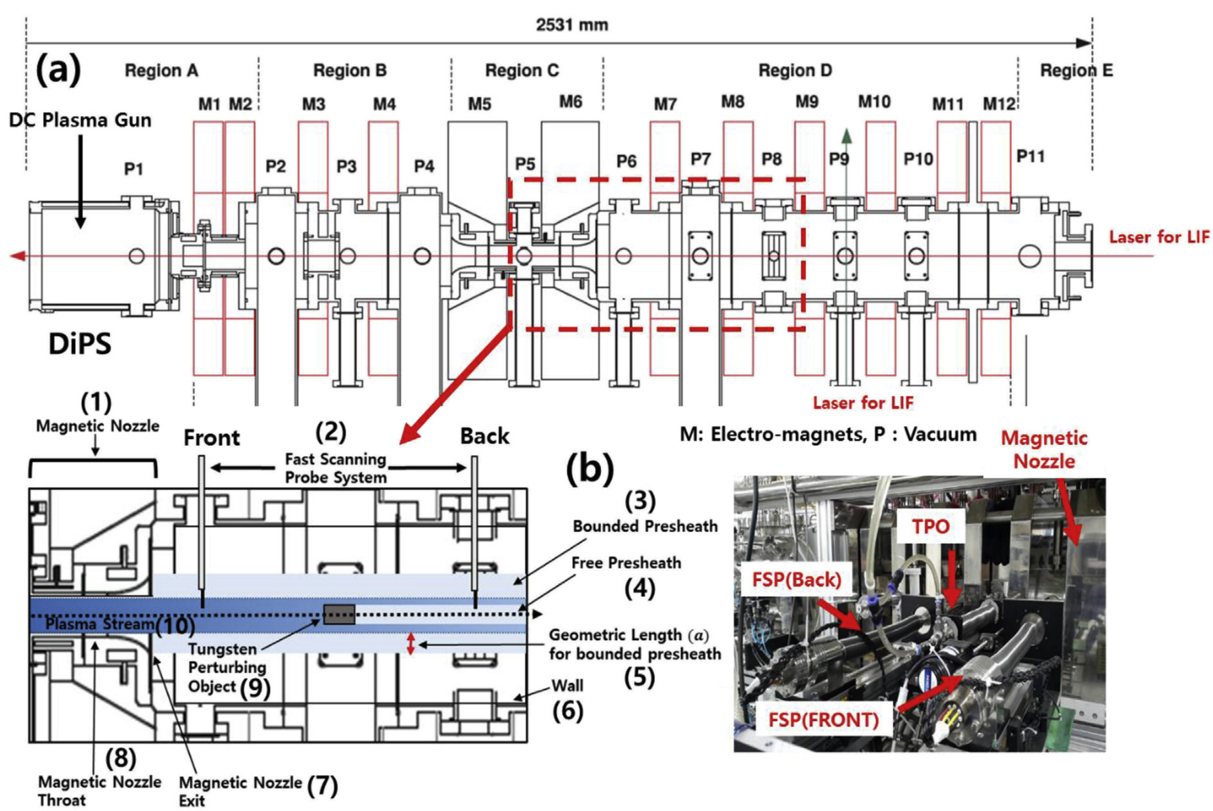

Fig. 1. (a) The schematic diagram of Divertor Plasma Simulator (DiPS) and (b) the experiment set-up to analyse diffusion coefficient ($D_{\perp}$) and characteristic length of perturbing for flux tube (L_c) in weakly magnetized plasma near a magnetic nozzle at DiPS. (1) magnetic nozzle, (2) fast scanning probe (FSP) system, (3) bounded presheath, (4) free presheath, (5) geometric length (a) for bounded presheath, (6) wall, (7) magnetic nozzle exit, (8) magnetic nozzle throat, (9) tungsten perturbing object (TPO), and (10) plasma stream. Geometric lengths (a) are radius (0.75 cm) of the TPO for a free preseath and the width (8 cm) between the outside of a magnetic nozzle throat and a magnetic nozzle exit for a bounded presheath.