Characteristic Formation of Edge Transport Barrier in the Compact Helical System

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The structure of the Edge Transport Barrier (ETB) was measured by means of a triple Langmuir probe in the Compact Helical System, this diagnostic method achieving high time and spatial resolutions. The radial profiles of electron temperature and electron density show a steep gradient inside the normalized minor radius $\rho \sim 0.96$, having a plateau of T_e at $0.96 < \rho < 1$ and a dip of n_e at $0.95 < \rho < 0.98$. The radial electric field clearly changed in the H-phase in the region at $\rho < 0.96$ and $0.99 < \rho < 1$, and its shear increased around $\rho \sim 0.97$. The characteristic profile evolutions suggest an interaction between ETB formation and a magnetic island related to $\iota/(2\pi) = 1$. Based on these data, the precise position of the ETB is not determined definitely; that is, it is not established whether it exists inside the magnetic island or closely inside the last closed flux surface ($\rho = 1$).

Keywords: edge transport barrier, L-H transition, Langmuir probe, radial electric field, magnetic island

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The Edge Transport Barrier (ETB) formed by L-H transition has been observed in the Compact Helical System (CHS) by controlling the rotational transform with large ohmic plasma current [1] and by two neutral beam injections (NBI) in co-direction without ohmic plasma current [2]. Detailed measurements of plasma parameters in the ETB region are crucial for clarifying the transition's mechanisms.

We have measured electron temperature (T_e), electron density (n_e) and space potential (V_s) simultaneously at high time (1 μs) and high spatial resolutions (~6 mm for poloidal, ~2 mm for radial) using a triple Langmuir probe (LP). The LP has five poloidally separated tungsten tips, each tip being a cylinder 0.5 mm in diameter and 2 mm in length. The five tips are used in the modified triple probe method [3]. This method measures two ion saturation current signals and two floating potential signals (V_f), and uses the average value for the reduction of measurement errors. The LP was moved radially shot by shot from the normalized radius $\rho \sim 0.93$ to 1.1 for reproducible ETB shots.

The experiments for ETB study were carried out in hydrogen plasmas, where absorbed NBI power by co-injection was about 800 kW and the toroidal field was $B_t = 0.88$ T at a magnetic axis position $R_{ax} = 0.92$ m. Figure 1 shows a typical discharge waveform of a plasma having an ETB. The L-H transition occurs spontaneously at $t_{tran} \sim 64$ ms. At the transition, H_α emission suddenly drops, and line averaged electron density measured by HCN laser interferometer ($\overline{n}_e$) rapidly rises. The rising density rate in the off-center chord ($\rho \sim 0.63$) is higher than that in the center chord. The typical time evolutions of T_e, n_e, V_f and V_s measured by LP, together with H_α, for four shots in this experimental campaign are shown in Fig. 2. Vertical lines indicate the transition in which H_α emission starts to drop, for each shot. After the transition, electron density and electron temperature inside $\rho \sim 0.96$ clearly increase. The floating potential clearly decreases to negative inside $\rho \sim 0.96$ and slightly increases outside the radial location. Note that the transition time in these four shots shown in Fig. 2 is not the same, but coincides within about 1 ms or less. Even if we take into account the difference of the transition time, these data indicate that the

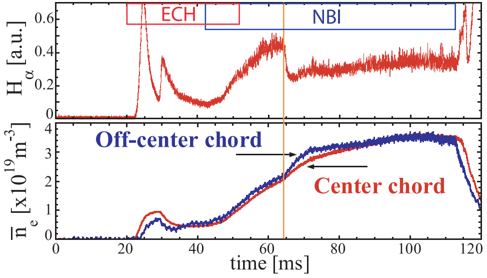

Fig. 1 Typical waveform of an NBI heated plasma with L-H transition.

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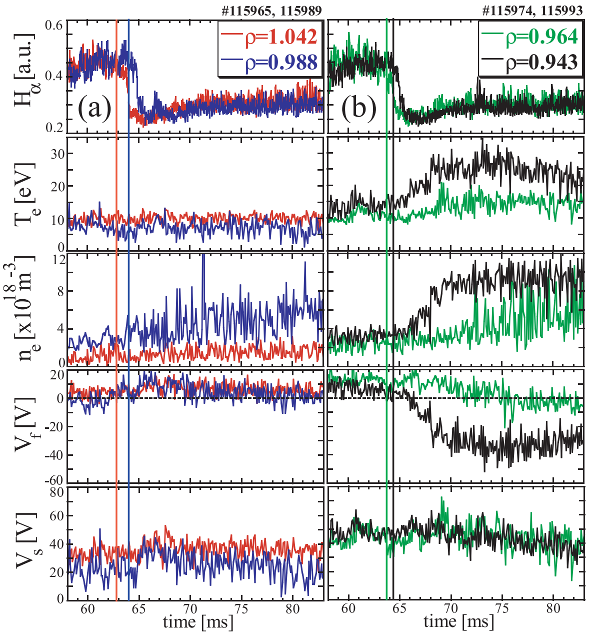

Fig. 2 Time evolutions of T_e, n_e, V_f and V_s measured by LP at (a) $\rho = 1.042$, 0.988 and (b) $\rho = 0.964$, 0.943, together with H_α, for four reproducible shots. The vertical lines indicate the transition in which H_α emission starts to drop, for each shot.

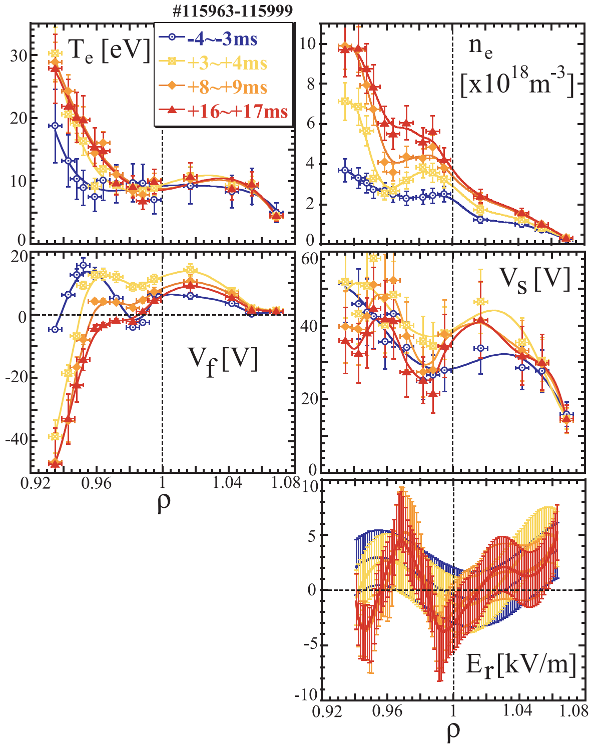

Fig. 3 Radial profiles of T_e, n_e, V_f, V_s and E_r at four time slices averaged over a 1 ms time window, where $t = 0$ stands for the transition.

change in the space potential V_s is less visible across the transition in contrast to that in V_f.

Figure 3 shows a comparison of the radial profiles of T_e, n_e, V_f, V_s and radial electric field (E_r) at four time slices averaged over a 1 ms time window. These profiles were obtained from 30 ETB shots with good reproducibility (as described above, the difference of the transition time among these shots is about 1 ms or less), where the time for each shot is adjusted to be $t = 0$ at the transition defined by the H_α-signal. Just after the transition ($t = +3 \sim +4$ ms), T_e's radial profile has a steep gradient inside $\rho \sim 0.96$, having a plateau of T_e at $0.96 < \rho < 1.0$. The electron densities inside $\rho \sim 0.96$ and around $\rho \sim 0.98$ obviously increase, exhibiting a steep gradient inside $\rho \sim 0.96$ and a dip of n_e at $0.95 < \rho < 0.98$. After that ($t = +8 \sim +9$ ms), the T_e profile evolves to a profile having a steep gradient inside $\rho \sim 0.98$. The hollow region of n_e is filled around $\rho \sim 0.96$. At $t = +16 \sim +17$ ms, the hollow structure of n_e almost disappears, and the steep gradient tends to develop inside $\rho \sim 1$. This peculiar edge structure seen in the T_e and n_e profiles may be linked to the presence of the magnetic island at $\iota/2\pi = 1$ ($\iota/(2\pi)$ is the rotational transform), where the position of the rational surface is calculated to be $\rho \sim 0.95$–0.96. These observations suggest that a steep gradient will be formed inside the magnetic island related to $\iota/(2\pi) = 1$ and that the flat profile of T_e and n_e inside the island may be kept. From these data, however, the position of the ETB has not been precisely determined; that is, it is not established whether it exists inside the magnetic island or closely inside $\rho = 1$.

It is generally thought that radial electric field E_r and its shear $\partial E_r/\partial r$ (E_r') play an important role in the formation of the ETB. The floating potential V_f is sometimes employed to obtain information about E_r and E_r' [4, 5]. The floating potential V_f inside $\rho \sim 0.96$ obviously changed from small positive to large negative, as seen in Fig. 3. On the other hand, V_f slightly increased outside the radial position. Similar results were observed in the past experiment in CHS [1] where only V_f was measured by a single LP. The space potential V_s is evaluated as $V_s = V_f + \alpha T_e$ having $\alpha \sim 3$ for hydrogen plasma, and should be used to derive E_r. The space potential V_s decreases in the region of $\rho < 0.95$ in the H-phase, where the n_e profile has a steep gradient. E_r was evaluated from the radial derivative of the fitted profiles of V_s. In the H-phase, E_r clearly changed in the region at $\rho < 0.96$ and $0.99 < \rho < 1$, and its shear became larger around $\rho \sim 0.97$. Thus, the E_r profile has a similarity to non-uniform E_r inside a magnetic island observed in LHD [6].

In conclusion, the formation of ETB with a plateau or dip near the rational surface of $\iota/(2\pi) = 1$ was observed. E_r and E_r' obviously changed in the H-phase. Measurements at different toroidal locations are necessary to confirm the presence of the island. This work is supported in part by a Grant-in-Aid for Scientific Research from JSPS, No. 15206107.

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