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On the Sensitivity of the Plasma Electric Potential to the Edge Transport Barrier Formation

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Abstract

The Heavy Ion Beam Probe (HIBP) diagnostics on T-10 tokamak was used for direct study the local values of the plasma potential in the ECR heated plasma. The Tl^+ ion beam with the energy up to 240 keV and intensity about a few dozens μA was used in experiments. The behavior of the bulk plasma potential and density was observed in the outer region with respect to EC resonance. Spontaneous improvement of plasma confinement (L-H transition) was studied. The fall down of the potential accompanies the fall of Dα and the line-averaged density increase. The formation of the transport barrier near the plasma edge was observed by the time evolution of the secondary beam intensity profile. The variations of the time scale of the transition were observed. During the L-H and H-L transitions the clear correlation between the rise of the edge density gradient and potential behavior was observed.

Keywords:

tokamak, transport barrier, plasma electric potential, HIBP

1. Introduction

The importance of the radial electric field E_r for the improved plasma confinement is well recognized now [1,2]. It is expected that E_r can help us to understand the underlying mechanisms that form transport processes in the plasma. It is known [2,3] that the change of the electric field is fundamental for the H-mode. The study of E_r during the transport barrier formation is the most desirable target for fusion research now. Regimes with edge and internal transport barriers have been obtained in tokamaks with elongated cross section and divertor mainly [4,5]. Recently they were obtained in the circular limiter tokamak T-10 with ECRH [6-11].

The Heavy Ion Beam Probe (HIBP) is the only diagnostics allowing us to investigate directly the plasma potential in the core and edge plasma. The local value of the plasma potential equals to the change of the beam energy in the sample volume. The intensity of the secondary beam indicates the local density.

This paper is focused in the experimental study of the link between the potential behavior and edge transport barrier formation.

We studied off-axis ECRH with plasma parameters $B_0 = 2.14$ T, $I_p \cong 280$ kA, $n_e \cong 1.2 \times 10^{13}$ cm^{-3}, $P_{EC} = 0.5$ MW, $a_{lim} = 30$ cm. The electron temperature $T_e(0) = 1.7$ keV was measured by Thomson scattering, the ion temperature $T_i(0) = 0.5$ keV was measured by NPA. The EC-resonance was located at $r = 16$ cm. The outer area (≥ 17 cm) was achievable for HIBP. The relative potential $\Delta\phi$ is studied with respect to the L-mode values at t_0:

$$\Delta\phi(r, t) = \phi(r, t) - \phi(r, t_0).$$

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2. The Potential Sensitivity to L-H Transition Details

When the ECRH power is in the vicinity of the threshold value, the long (dozens of milliseconds) preliminary phase often precedes the transition to the improved confinement. It is characterized by irregular falls of Dα intensity and increases of the line-averaged density. Figure 1 (#24347) shows that in the preliminary phase of the transition, the plasma potential in the inner point r = 17 cm drops simultaneously (within the accuracy of the time resolution of potential measurements: 20 ms here) with Dα drop. Figure 2 (#24358) shows that if the Dα intensity returns to the L-mode value, the plasma potential in the point r = 22 cm also returns to the L-mode value. This shows that plasma potential is very sensitive to the details of the transition process both in the dithering preliminary phase and in the regular H-phase.

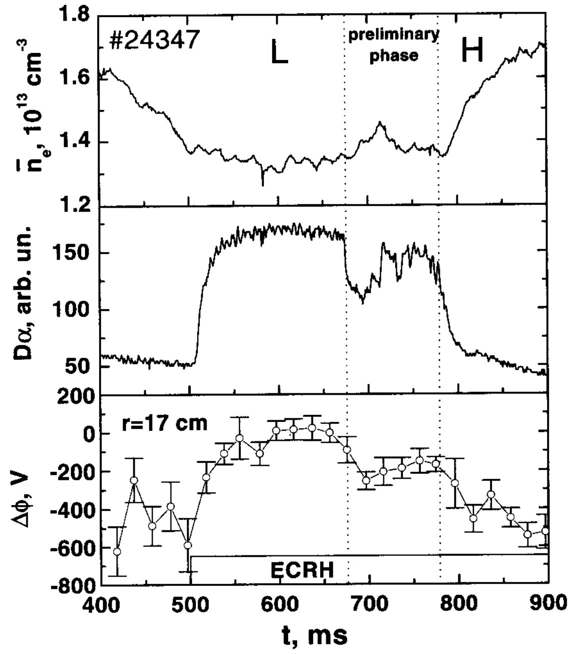

Fig. 1 Time evolution of the shot with a long preliminary phase before improvement of confinement.

3. Coupling of the Potential Profile Evolution and the Edge Density Barrier Formation

Figure 3 presents the time history of two shots with different ECRH power. In both cases ECRH starts at t = 500 ms and lasts till 900 ms. The case of lower power (#26186, P_{EC} = 0.22 MW, dashed lines) is characterized by long L-phase, where the potential $\Delta\phi$ at r = 23.5 cm ($x = r/a$ = 0.78) is almost constant. It starts to decrease at the beginning of the preliminary phase with the density increase (t_H^{86} = 680 ms). The absolute change of potential is –300 V. Later on at the L-H transition (t = 740 ms) the potential has the next step of decrease, –200 V more.

In the case of higher power (#26185, P_{EC} = 0.35 MW, solid lines) the L-mode phase is short (500–540 ms), the preliminary phase takes 540–610 ms, and the H-phase starts at t_H^{85} = 610 ms. In the preliminary phase Dα starts to fall down and oscillates between L and H levels (Fig. 3b), while density may (or not) start to rise and fall (Fig. 3a). After the short L-phase, the potential starts to fall down at the preliminary phase and later on at the H-phase (Fig. 3c). Four important time instants are marked on Dα evolution. Profiles of the plasma potential measured in these instants are presented in Fig. 4. One can see formation of the edge layer with the high electric field.

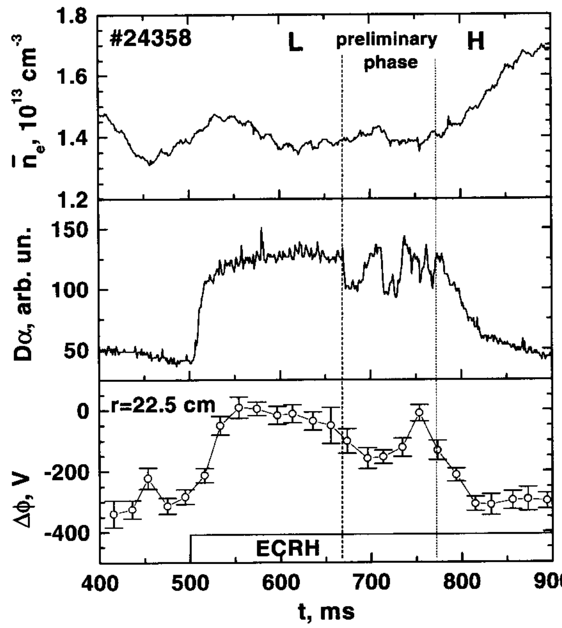

Fig. 2 Time evolution of the shot #24358. In the preliminary phase of the H-mode, Dα signal, the plasma potential and line-averaged density returned to the L-mode values.

HIBP is sensitive to the plasma density. The total secondary ion current is proportional to the local plasma density $I_{tot} \sim nf(T_e)$ (the attenuation factors can be neglected here). The time evolution of the relative value of I_{tot} with respect to the L-phase value is presented in Fig. 5. It shows the rapid increase of the density

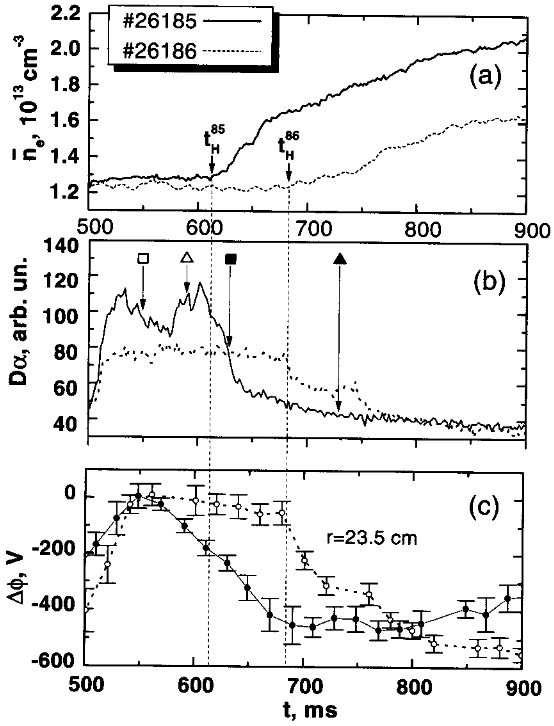

Fig. 3 Time evolution of the shots with different ECRH power: #26186, low power P_{EC} = 0.22 MW (dashed lines), the L-phase is long (500–680 ms), the preliminary phase takes 680 – 740 ms, the H-phase starts at t_H^{86} = 680 ms; #26185, higher power P_{EC} = 0.35 MW (full lines), the L- phase is short (500-540 ms), the preliminary phase takes 540-610 ms, the H-phase starts at t_H^{85} = 610 ms. (a) the density, (b) Dα intensity, (c) the relative plasma potential. □, △, ■ and ▲ denote the time instants, where the potential profiles were measured.

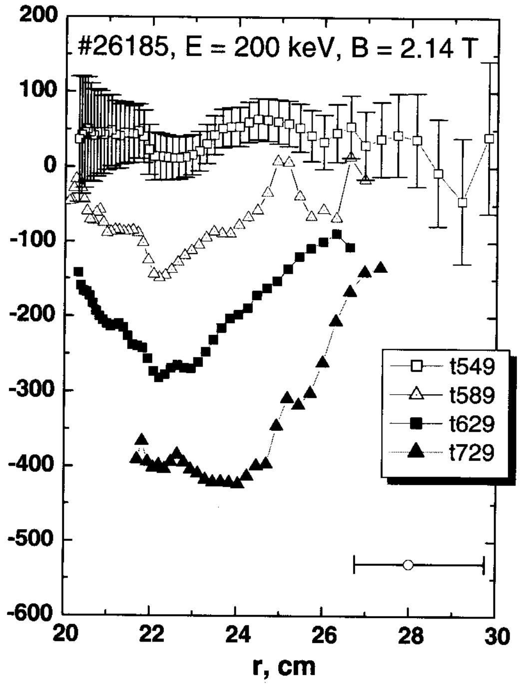

Fig. 4 Potential profiles in the time instants shown in Fig. 3. Formation of high electric field (increasing of the slopes at the edge) during the L-H transition is seen. Horizontal bar shows the radial uncertainty of the family of profiles as whole.

gradient during the transition. It indicates formation of the edge transport barrier. Drop of the signal from inner radii on the latter curve (t = 729 ms) may be explained by the further rise of density and appearance of the attenuation factors, which decrease I_{tot}.

The outer chord densities observed by interferometer also indicate formation of the edge density barrier by the rise of inner signal along with some fall of outer one (Fig. 6).

4. L-H and H-L Transitions

Figure 7 presents the time history of the line-averaged density (a) and Dα emission (b) in the shot #27538. The H-mode starts at 600 ms and lasts till the switch-off one from three gyrotrons at 635 ms. It still remains in spite of the deposited ECR power decrease. At 690 ms, KCl pellet injected from the low field side initiates the H-L transition. The L-mode remains till the end of the ECRH pulse (812 ms). The final Ohmic phase has the higher density with respect to initial one. Evolution of the plasma electric potential $\Delta\phi$ at r = 23.5 cm is presented in Fig.7 (c). During the ECRH pulse, the potential shows clear rise with respect to its Ohmic level. At the L-H transition, the potential drops down to the initial Ohmic value. At the H-L transition, the potential rises up towards its L-mode level. At the final Ohmic phase, the potential comes back to the initial Ohmic level and even lower.

Figure 8 shows the time evolution of the potential profile respectively to L-mode values. The time variation of the profile shows three phases:

1. the initial Ohmic phase, 533 ms;
2. the L-mode, 593 ms, - reference curve;
3. the H-mode phase, 653 ms, when the inner potential falls down to –300 V and the limiter potential remains the same. This forms the layer (about 1 cm) with the strong E_r. This layer remains the same during the Dα drop. The potential profile is very close to the one in Ohmic phase;
4. the L-mode after KCl pellet injection, 713 and 773 ms. At 713 ms the edge layer with the strong E_r was destroyed. Potential profile is close to the one in L-

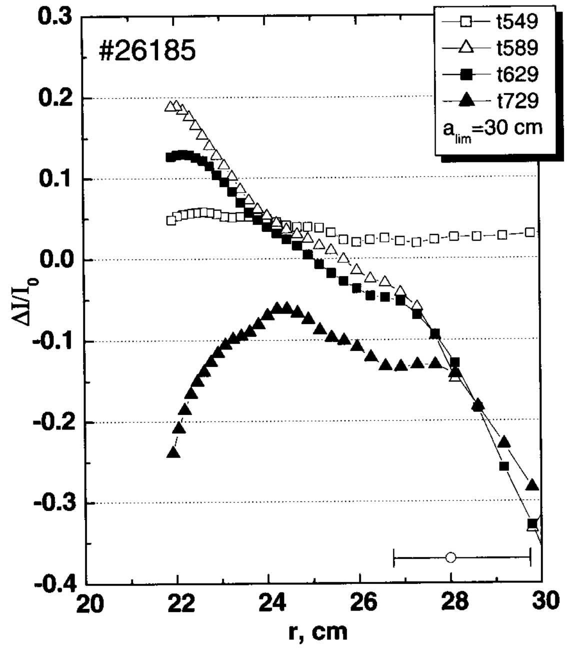

Fig. 5 Evolution of the secondary beam current, which proportional to the plasma density. During the L-H transition the absolute values of the density and their gradients increase.

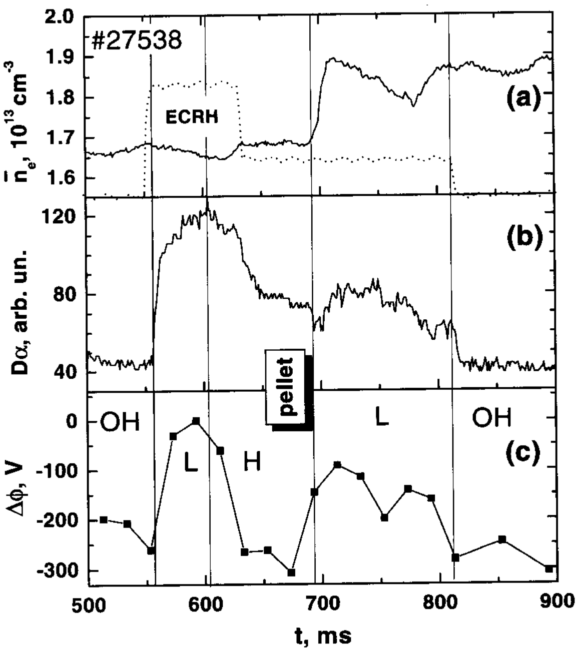

Fig. 7 The shot with the L-H transition at t_H = 610 ms and the H-L transition forced by KCl pellet injection.

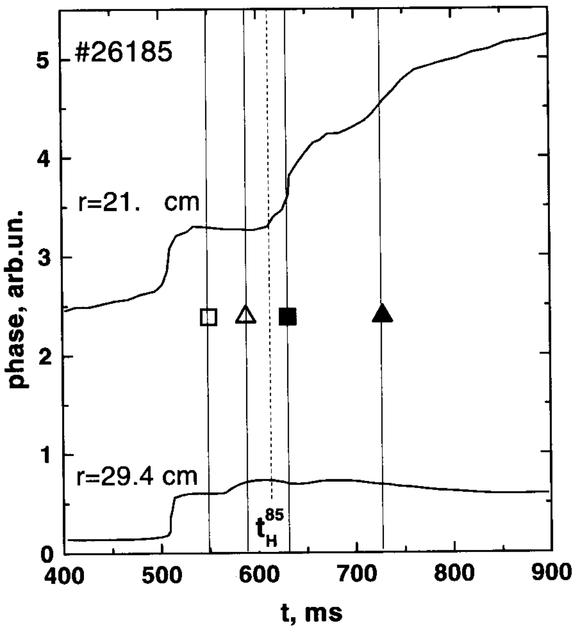

Fig. 6 Raw interferometer data for two outer chords (low field side). Indicates formation of the edge density barrier after t_H^{85} = 610 ms.

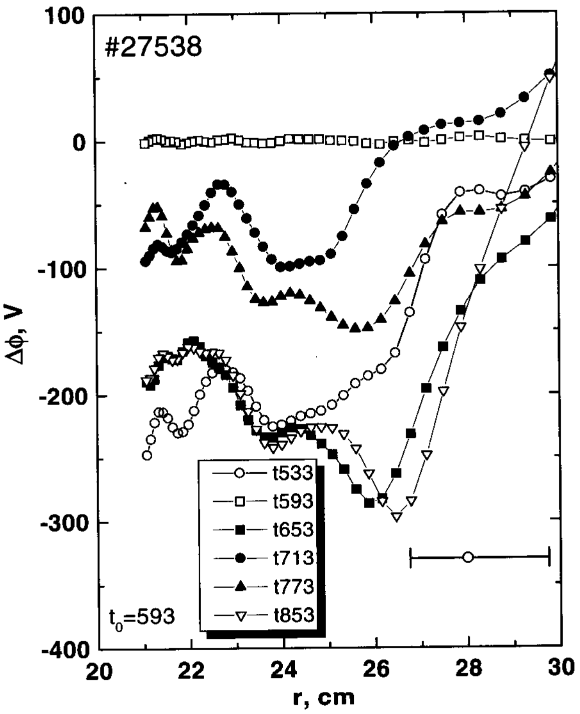

Fig. 8 The extra potential profile evolution in the shot from Fig. 7.

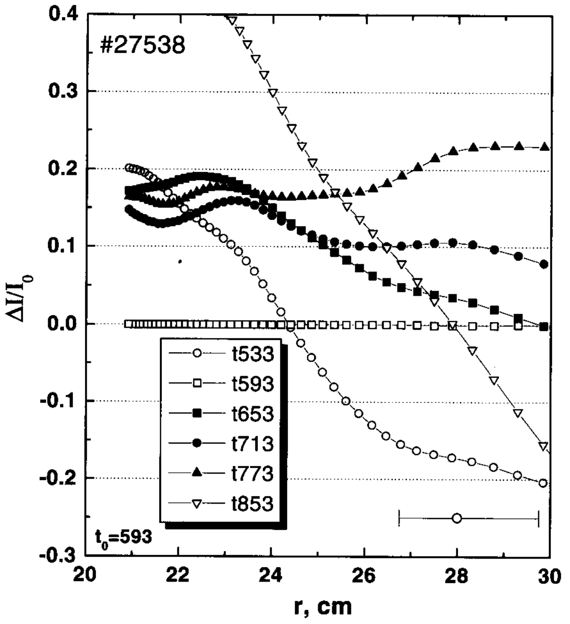

Fig. 9 Secondary beam current profile evolution in the shot from Fig. 7.

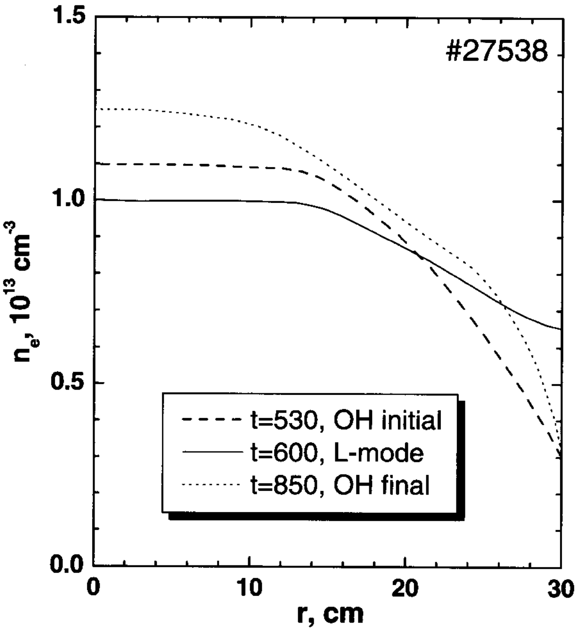

Fig.10 Density profiles reconstructed from interferometer data.

mode;

5. the final Ohmic phase, 853 ms. Potential profile is very close to the one in the initial Ohmic phase and H-phase.

The time evolution of the relative value of I_{tot} with respect to the L-mode values is presented in Fig. 9. It shows the rapid increase of the density gradient during the L-H transition (t = 653 ms), which indicates formation of the edge transport barrier. After the H-L transition, the slope is flattening, that indicates destruction of the density barrier (t = 713, 773 ms).

It should be noted that OH phase has a higher density gradient than the L-mode. In the final OH phase the density gradient is steeper than in the initial one (t = 533 ms). This observation is in a quantitative agreement with the density profile reconstruction from interferometer data, presented in Fig. 10.

5. Conclusions

Edge density barrier formation and behavior of the plasma potential were studied during the spontaneous L-H transition in off-axis ECRH heated plasma on T-10 tokamak. From our observations we can summarize the following features of the potential behavior during the edge barrier formation.

Time evolution of the local plasma potential in the inner points correlates with Dα intensity: both rise up and drop down simultaneously.

In the regimes under study the time scale of the potential decay may vary from 150 ms to less than 20 ms.

Edge transport barrier formation detected by the secondary ion current profile correlates with increase of the negative extra edge radial electric field.

After ECRH start, the bulk plasma potential changes to more positive values with respect to OH level. After the L-H transition, the plasma potential profile comes back close to OH values.

Acknowledgments

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