

## Behavior of the plasma electric potential during the internal and external transport barriers formation

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The plasma potential profile was measured on the T-10 tokamak ( $R = 150$  cm,  $a = 30$  cm) by the Heavy Ion Beam Probe (HIBP) diagnostics in the regimes with the external (H-mode) and internal transport barriers (ITB).

The diagnostic  $Tl^+$  beam with the energy up to 250 keV and intensity of about a few dozens  $\mu A$  was used to probe the outer half of the plasma column in the low field side.

This paper reports the HIBP study of the regimes with electron ITB obtained by off-axis ECRH/ECCD (140 GHz, 0.5-0.8 MW) with  $B = 2.1 - 2.14$  T,  $I_p = 200 - 330$  kA,  $q_{lim} = 2.4$  [1]. We investigate the extra potential values with respect to initial steady state phase (L-mode). The time evolution of the extra potential profile was obtained by the periodical scan of the beam injection angle. The power supply system provides the 7 ms scan every 20 ms.

In the previous experiments we have investigate the regime with the external transport barrier (H-mode)  $B = 2.28$  T,  $I_p = 160$  kA,  $a_{lim} = 25$  cm,  $q_{lim} = 3$ . It was shown that during the L-H transition the peripheral plasma potential forms narrow layer with strong electric field ( $\sim 300$  V/cm) in the vicinity of the limiter [2]. Figure 1 shows the time evolution of the plasma parameters in the in with H-mode in comparison with the reference one. One can see that the fall of the plasma potential occurs simultaneously with the typical H-mode features: increase of the line-averaged density and fall of  $D_\alpha$  emission. The local potential in the observed point with  $r = 18$  cm falls down simultaneously with increase of  $n_e$  and fall of  $D_\alpha$ . The observed sample volume was located in between the edge barrier ( $r = 23-24$  cm) and the region of EC resonance ( $r = 14$  cm). The local plasma potential in the inner point correlates with  $D_\alpha$  intensity:  $D_\alpha$  and potential rises up and falls down similarly.

Figure 2 presents the typical time evolution of the extra potential profile in the L-H transition with respect to the L-mode level. The narrow (width about 1.5 cm) layer with a strong electric field is formed just near the limiter. The potential fall is about -400 V.

Figure 3a shows the  $T_e$  profiles measured both by Thomson scattering and ECE methods after and before the transition. It shows the formation of the steep gradient on the  $T_e$  profile at the region of EC resonance ( $r \sim 16$  cm). Figure 3b shows the time evolution of the potential profile. During the electron ITB formation the plasma extra potential forms the transient local deep negative well with maximum value up to -1000 V in the vicinity of the internal barrier. This local well disappears in the post-barrier steady state.

The reference values were found at the initial steady-state phase. The presented profile was obtained as the combinations of the two parts measured in two similar discharges with the beam energies  $E_b=240$  keV and  $E_b=210$  keV. The observed radial intervals overlap in about 1 cm.

It was shown in [1] that in the discussed regimes the electron ITB formation correlates with potential fall, drop of  $D_\alpha$  and increase of line-averaged density  $n_e$ .

The area of observation was limited by the diagnostic restrictions. To observe the outer part of the plasma the beam energy was changed to  $E_b=170$  keV.

The temporal evolution of the outer part of the plasma potential profile in the shot #26176 with ITB is presented in Fig. 4. The area of the sharp decrease of the plasma potential just near the limiter appears to be similar to the one shown in Fig. 2.

HIBP is sensitive to the plasma density. The total secondary ion current is proportional to the local plasma density  $I_{tot} \sim n f(T_e)$ . The beam attenuation can be neglected at the plasma edge. The time evolution of the relative value of  $I_{tot}$  with respect to the initial steady state value presented in fig. 6 in the form of  $(I(r) - I_0(r))/I_0(r)$ . It shows that the edge density gradient increases during the transition. It indicates the formation of the edge density barrier. Therefore, in discussed regimes the edge density barrier (H-mode) also appears altogether with ITB.

The time trace of the line-averaged plasma density and the electron temperature measured by the second ECE harmonic at  $r = 17$  cm just inside the ITB are presented at the Fig. 5. The plasma potential at the periphery in ITB regimes shows the clear correlation between the potential drop and  $D_\alpha$  drop (Fig. 5). Therefore, in discussed regime the external density barrier (H-mode) is forming simultaneously with the internal electron barrier within the accuracy of the time resolution of the measurements (1 ms for  $T_e$  and  $D_\alpha$ , and 20 ms for potential).

During the edge and internal transport barriers formation the local potential near both barriers behave similar: when the density rises up the potential falls down, when the density keeps constant the potential rises up, the post-barrier steady-state extra potential profile with respect to the pre-barrier steady state has the stair shape with a sharp jumps  $\Delta\phi \sim -400$  V near the barriers.

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## References

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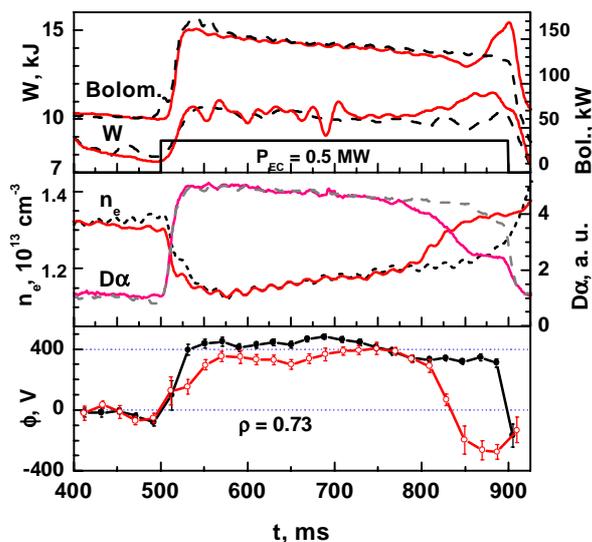


Fig. 1. Time traces of some plasma parameters in the shot with H-mode, #23702,  $I_p = 152$  kA (full lines), and with the L-mode one, #23706,  $I_p = 158$  kA

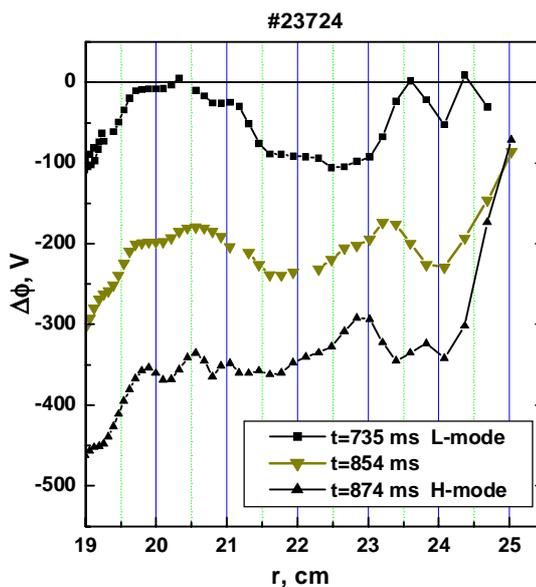


Fig. 2. The temporal evolution of the potential profiles with respect to the initial steady state phase in the shot with H-mode.

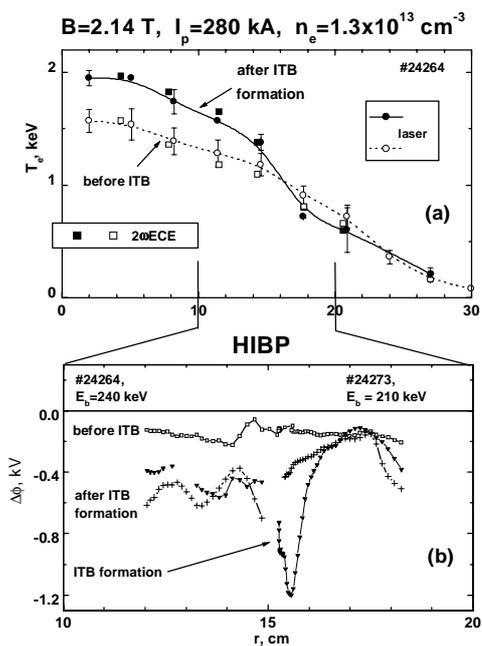


Fig. 3. The electron temperature profiles (a) and the plasma potential (b) in the shots #24264 and #24273 with internal transport barrier (ITB); before ITB ( $t=753$  ms), during ITB formation ( $t=853$  ms) and after ITB formation ( $t=893$  ms).

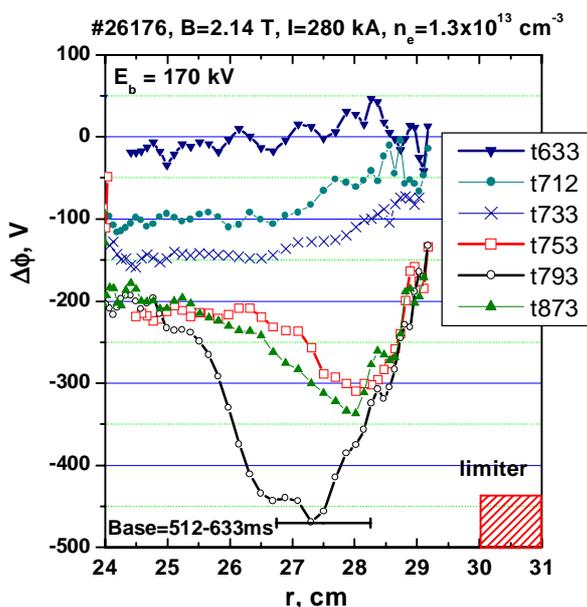


Fig. 4. The temporal evolution of the plasma potential in the shot #26176 with ITB. Horizontal bar shows the uncertainty of radial reference

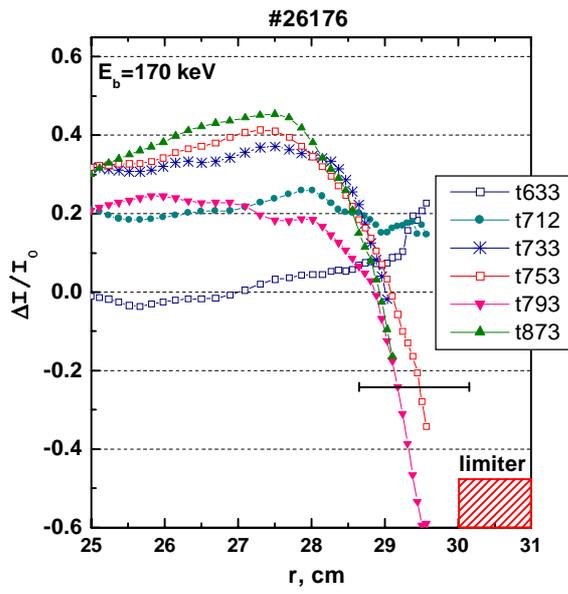


Fig. 5. The temporal evolution of the shot # 26176 with ITB.

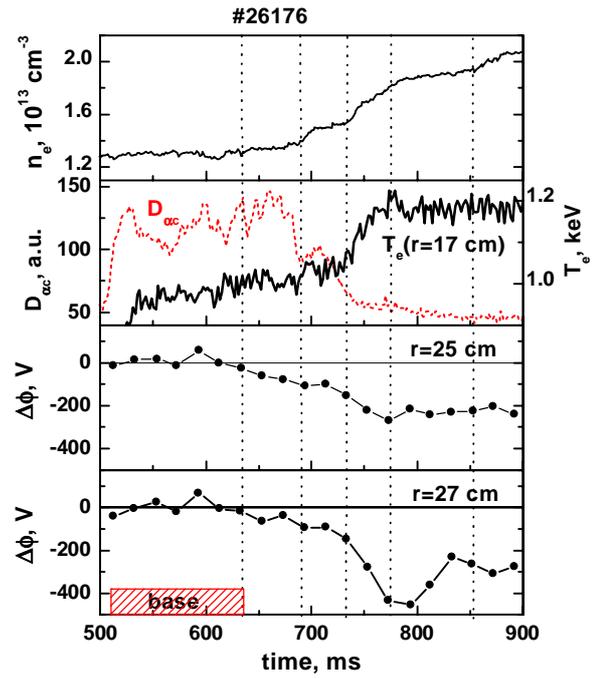


Fig. 6. The temporal evolution of the beam current. Indication of the formation of the density barrier in the H-mode.