Instantaneous Correlation between ELM-like MHD Activity and Abrupt Non-local Reduction of Transport at Internal Transport Barrier Formation in JT-60U High-β_p Plasmas

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Abstract

Transport evolution in normal and reversed shear JT-60U tokamak plasmas with internal transport barrier (ITB) often occurs via non-local transport bifurcations. In the present paper, we highlight new type of edge-core instantaneous interplay in JT-60U high-β_p plasmas. Abrupt in time (ms timescale) and wide in space (~0.4 of minor radius) reduction of electron heat flux in the core (ITB-event) is correlated in ms timescale with the start of an ELM that creates enhanced level of H_α. This result gives a hint of the control to form the ITB immediately and non-locally by inducing the ELM-like MHD activity.

Keywords:

internal transport barrier, ITB-event, non-local transport bifurcation, ELM

Over the past few years, a significant progress has been achieved in the development of the steady state high-β_p scenario with Normal magnetic Shear (NrS) and the Reverse Shear (RS) scenario [1,2] in JT-60U plasmas with Internal Transport Barrier (ITB). Understanding the properties of ITB and identifying the control method of ITB are among the most important issues for the tokamak fusion research. Possible feedback loops between the increase of pedestal pressure and core confinement, and further improvement of edge stability were reported for high-β_p JT-60U plasmas [1]. Abrupt in time (ms timescale) and wide in space (~0.3 of minor radius around outer edge of weak ITB) variations of electron heat diffusivity in JT-60U RS plasmas were reported earlier and called "ITB-events" [3,4]. The ITB-events (i.e. improvement or degradation of confinement) are observed as simultaneous rise and decay of electron and ion temperatures $T_{e,i}$ in two spatial zones.

In the present paper, we analyze the ITB evolution in a high-β_p 1.5 MA/3.8T discharge E34487 (see some timetraces also in [5]). Timetraces of this discharge are shown in Fig. 1(a); the injected neutral beam power P_{nb}, stored energy W, and ion temperature T_i at $r/a \approx 0.4$. The time trace of H_α and the T_e evolution are presented in the same figure. The T_e was measured by ECE heterodyne radiometer with 12 channels inside the region $0.29 \le r/a \le 0.67$. In order to clearly see the T_e evolution at the ITB-event improvement I at t = 4.602 s (shown by vertical lines in Figs. 1(a) and (b)), values of T_e shown in Fig. 1(b) are shifted vertically to each other (absolute scale is the same for all channels). Radial profiles of T_i (circles) and T_e (squares) measured just before t = 4.6 s are shown in Fig. 2(a) together with q profile measured with MSE. The plasma evolution shown in Figs. 1(a) and (b) is briefly described as follows. A weak ITB is created before 4.6 s. The ITB foot is clearly observed in the T_i profile at t = 4.6 s as

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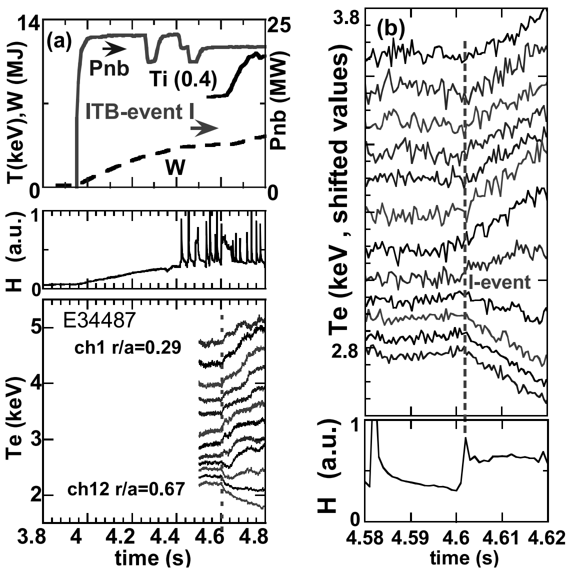

Fig. 1 (a) Evolutions of T_i, W, P_{nb}, H_α and T_e. (b) T_e and H_α evolutions around ITB-event I. Millisecond scale correlation between H_α rise and abrupt change of $\partial T_e/\partial t$ is observed.

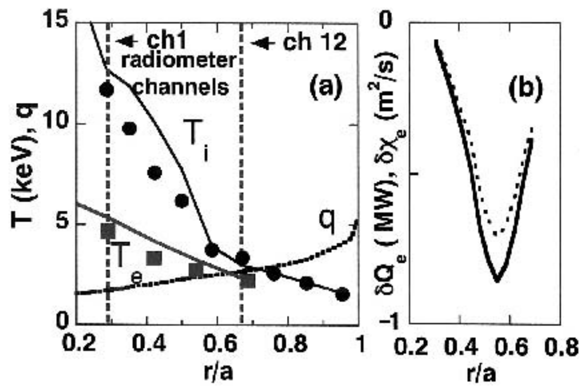

Fig. 2 (a) Radial profiles of T_i (circles), T_e (squares), and q (dotted line) at t = 4.601 s, and profiles of $T_{i,e}$ 90 ms after ITB-event I (solid lines). (b) Profiles of electron heat flux jump δQ_e (solid line) and χ_e jump $\delta\chi_e$ (dotted line) calculated from $\delta(\partial T_e/\partial t)$ at ITB-event I.

shown in Fig. 2(a). ELMs start at ~4.4 s (see Fig. 1(a)). The edge condition at this time corresponds to the ELMy H-mode. Just after the start of an ELM the ITB-event I is observed as an abrupt rise of T_e at channels 1–8 and its decay at channels 9–12 (discontinuous jump of $\partial T_e/\partial t$, $\delta(\partial T_e/\partial t)$, in ms timescale). The appearance of $\delta(\partial T_e/\partial t)$ correlates well (in ms timescale) with the rise of H_α (see Fig. 1(b)). The value of ∇T_e varies locally at inversion radius only (between channels 8 and 9). We can interpret this ITB-event as the ITB "improvement" or, at the same time, the formation of stronger ITB out of the weak one. The variation of $\partial T_e/\partial t$ and $\partial T_i/\partial t$ at the ITB-event I allows us to estimate the jumps of electron and ion heat fluxes, δQ_e and δQ_i, separately (see [3,4] for detail). Figure 2(b) shows the profile of δQ_e calculated from $\delta(\partial T_e/\partial t)$ at the ITB-event I. The power balance calculations performed with a 1.5 dimensional transport code TOPICS [6] show that the total diffusive heat flux via electron and ion channels is equal to 3 MW at r/a = 0.45 while $\delta Q_e + \delta Q_i \approx -2$ MW at the same radius. The total diffusive heat flux is then reduced as much as 2.5~3 times at this ITB-event I. The profile of electron heat diffusivity variation ($\delta\chi_e$) at ITB-event I is shown by dotted line in Fig. 2(b). After ~30 ms, the transport first increases and then again decreases (see deceleration and acceleration of T_e rise in Fig. 1(a)). Hence the $T_{e,i}$ profiles of at t = 4.69 s shown by solid lines in Fig. 2(a) do not represent the evolution with continuously low transport level after the ITB-event I.

The formation of local ITB was preceded by the fishbone activity on the q = 2 surface in ASDEX Upgrade [7]. The level of heat flux reduction and the width of the region were not analyzed. The non-local abrupt bifurcations of transport at fast "global" L-H-L transitions were found in JT-60U NrS and RS plasmas with and without ITB (see [8] and references therein). ITB-event degradation triggered the L-H transition.

In the present paper, the heat flux outside the ITB decreases just after the rise of H_α. The jump of $\partial T_e/\partial t$ appears simultaneously (ms timescale) near the ITB, which represents abrupt (in ms timescale) reduction of the electron heat diffusivity inside wide region ($0.3 \le r/a \le 0.7$) concurrently with the rise of H_α. This correlation suggests the new type of "global" edge-core connection. At the same time, ∇T_e value varies locally at the inversion radius only (between the regions of T_e rise and decay). The total diffusive heat flux (at electron and ion channels) is reduced by ~3 times at the ITB-event I. This result gives a hint of the control to form the ITB immediately and non-locally by inducing the ELM-like MHD activity.

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