§18. Dynamics of Ion Internal Transport Barrier in LHD Heliotron

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In LHD, the ion internal transport barrier (ITB) appears when the P-NB is injected before the N-NB but not when the N-NB is injected before the P-NB, even if the power of the P-NBI and the N-NBI are identical later in the discharge. The T_e/T_i ratio at the time both P-NB and N-NB are injected is larger in the discharges with prior N-NBI rather than the discharges with prior P-NBI. These observations suggest that the high T_e/T_i ratio contributes to prevent the formation of the ion ITB in LHD. Therefore it is important to keep the T_e/T_i ratio close to or below unity at the onset of the high power NBI to achieve a high ion temperature. There are two approaches to achieve high ion temperature plasmas by keeping the T_e/T_i ratio at a low level in LHD. One is to perform the P-NBI injection only before the start of high power heating, which gives a target plasma with a low T_e/T_i ratio. The other approach is pellet injection before the start of high power heating, which results in a T_e/T_i ratio close to unity. There are two type of pellets: one is a hydrogen fueling pellet and the other is a carbon pellet. The carbon pellet has an additional benefit in increasing the power deposition of NBI to ions through ion-impurity collisions.

Figure 1 shows the time evolution of the ion temperature gradient at various radii and the normalized ion temperature gradient of R/L_{Ti}, where R is the major radius and L_{Ti} is the scale length of the ion temperature gradient defined as $-(1/a)(\partial T_i/\partial \rho)$. As seen in Fig.1(a), the ion temperature gradient starts to increase at approximately half of the plasma minor radius ($\rho = 0.44$), then the ion temperature gradient farther inside ($\rho = 0.26$) increases later. The ion temperature gradients at $\rho = 0.44$ reach up to 9 keV/m and decrease gradually before the ion temperature gradient further inside reaches the maximum value. The mechanism of this gradual decrease of ion temperature gradient is not well understood yet. The ion temperature gradient near the plasma center ($\rho = 0.17$) jumps to values twice of the L-mode value at 0.2 sec after the transition to an ion ITB, which is much longer than the energy confinement time. The normalized ion temperature gradient, R/L_{Ti}, evaluated just inside the foot at $\rho = 0.53$, jumps from 7 to 14 associated with the formation of the ion ITB [Fig.1(b)]. The time for the transition estimated from the time for the change of the R/L_{Ti} value is 0.1sec, while the ITB region expands to the inner side gradually ($\sim$ 0.2s).

As seen in Fig.1(c), the ion temperature decreases slightly in the outer region at $\rho > 0.6$, although the ion temperature in the core region at $\rho < 0.6$ increase significantly. The radial profiles of deposition power to ions plotted in Fig.1(c) are peaked in the plasma center both for P-NBI and N-NBI and the deposition power due to N-NBI is twice of the deposition power due to P-NBI. The deposition powers both of N-NBI and P-NBI decrease in time because of the decrease of the density during the decay phase of the carbon pellet. The radial profiles of thermal diffusivity at t = 2.10s (in the L-mode phase), t = 2.23s (just after the formation of ITB) and t = 2.33s (in the steady-sate phase of ITB) are plotted in Fig.1(d). The reduction of the thermal diffusivity is observed in a wide interior region of the plasma ($0.25 < \rho < 0.75$) after the formation of the ITB. The drop of the thermal diffusivity has a maximum at a half of the plasma minor radius and the reduction of the thermal diffusivity is by a factor 2. It should be also noted that the thermal diffusivity even slightly increases outside the ITB region ($\rho < 0.25$ and $\rho > 0.75$) just after the formation of the ITB. Later in the ITB-phase, the ITB region expands towards the plasma center and the reduction of the thermal diffusivity is observed near the plasma center ($\rho = 0.17$), in the steady-sate phase of the ITB.

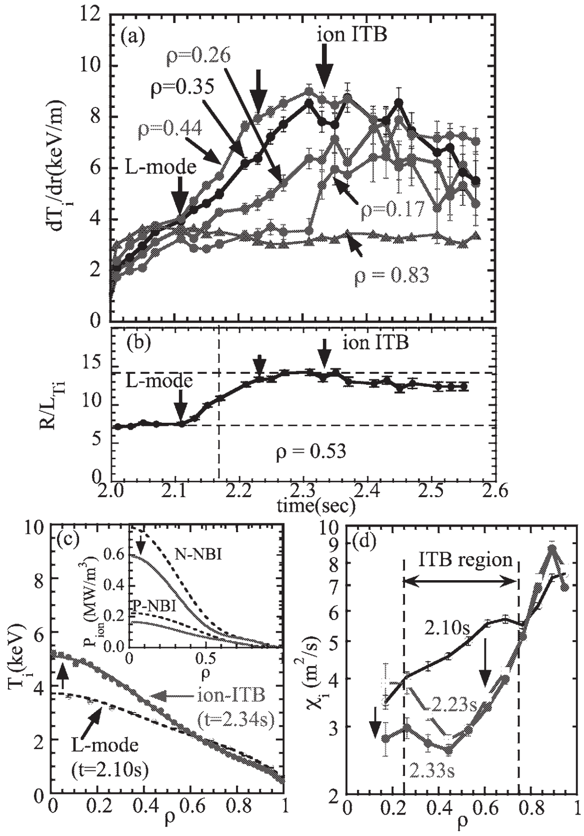

Fig. 1: Time evolution of (a) ion temperature gradients at various normalized radii and (b) R/L_{Ti} during the formation of an ITB and (c) radial profiles of ion temperature and deposition power to ions by P-NBI and N-NBI at t = 2.1s (L-mode : dashed lines) and t = 2.34s (ion-ITB : solid lines) and (d) radial profiles of ion thermal diffusivity at t=2.13s (L-mode), t=2.23s (early phase of ion-ITB) and t=2.33s (later phase of ion-ITB) in the discharge with carbon pellet injection (♯90982)