§5. Internal Transport Barrier Formation Triggered by Modulation Electron Cyclotron Heating in LHD

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Understanding of improved confinement modes is regarded as a key factor to realize thermonuclear fusion reactor. Spatiotemporal dynamics of internal transport barrier (ITB) formation is not fully understood yet. In the Large Helical Device (LHD), the ITB is observed associated with the electron root discharge where the neoclassical transport is reduced due to strong radial electric field[1)]. In the 18th experimental campaign, heating power modulation experiment in the ITB plasma is successfully performed, aiming to investigate the dynamics of ITB formation. By observing temporal response of the radial gradient of electron temperature measured with Thomson scattering, one can assess the dynamics of the ITB formation.

The experiments were performed with three units of electron cyclotron resonant heating (ECH) and four units of neutral beam injection (NBI). One ECH was used for heating modulation. Sequential heating modulation that was deposited in the core region was performed with the frequency of 19 Hz. Figure 1 shows radial profile of the electron temperature, at five different phases of modulation ECH (MECH) in the discharge we analyzed (#130039). The time interval t = 4.1-6.1 s is analyzed here. During the time interval, the line averaged electron density was almost constant in time. Other experimental parameters were follows: the magnetic axis of R_{ax} = 3.53 m, toroidal magnetic field of B = -2.8045 T, and line averaged electron density of $\langle n_e \rangle \sim 1 \times 10^{19}$ m^{-3}.

The Thomson scattering in LHD has a measurement frequency of 30 Hz. By use of conditional average, where we assume the perfect reproducibility of time evolution of the ITB formation at different period of MECH, the time sequence of the ITB formation is reconstructed. Figure 2 shows the result of conditional average at $r_{eff}/a_{99} \sim 0$, where the value of the horizontal axis is relative time τ with respect to the phase of MECH. Vertical scattering of the points comes from incomplete reproducibility in conditional average. Non-sinusoidal waveform is clearly shown with the method, although the scattering of the points to some extent appears. Spatiotemporal evolution of electron temperature gradient is quite complicated. At $r_{eff}/a_{99} < 0.3$ and $0.5 < r_{eff}/a_{99} < 0.7$, gradient increases as MECH is applied, whereas it decreases at $0.3 < r_{eff}/a_{99} < 0.5$. Using Thomson scattering, information from the core region is available, which is an obvious advantage compared with the ECE radiometer measurement at the present experimental condition.

With the deposition profile of MECH evaluated with a ray tracing code, energy conservation equation is solved to obtain heat flux[2)]. By describing the flux-gradient relation, a clear improvement of transport coefficient is seen, which is a feature of the ITB formation. Improvement of confinement is observed at $r_{eff}/a_{99} < 0.2$.

Fluctuation component of electron temperature is also observed with the ECE radiometer. When the ITB is formed, amplitude of low frequency MHD oscillation increases at $0.4 < r_{eff}/a_{99} < 0.7$. Around the location where the increase of the electron temperature oscillation is observed, the gradient is modulated with the ITB formation as was mentioned, which might cause the increase of the linear growth rate of the MHD mode.

In summary, time sequence of ITB formation was observed with modulation ECH. Thomson scattering with conditional average was used to reconstruct radial profile of time sequence of electron temperature. Improvement of confinement and following increase of MHD amplitude were observed.

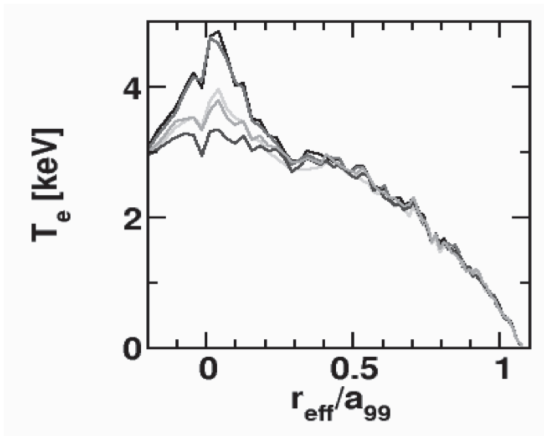

Fig. 1. Radial profiles of electron temperature measured with Thomson scattering at five different phases of MECH.

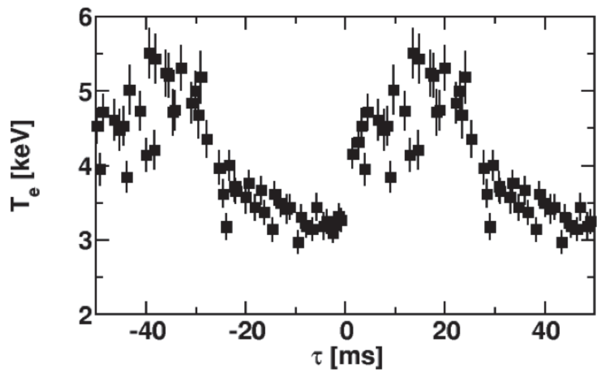

Fig. 2. Conditional averaged time evolution of Thomson scattering signal at $r_{eff}/a_{99} \sim 0$, showing ITB formation.

1) Ida K, et al.: Phys. Rev. Lett. **91** (2003) 085003.
2) Inagaki S. et al.: Nucl. Fusion **53** (2013) 113006.