§52. Observation of a Clear Transition to High-T_e State with an Electron ITB in EC Heated LHD Plasmas

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A transition to a high electron temperature state in the core accompanied by an electron internal transport barrier (eITB) was clearly observed in neutral beam (NB) sustained plasmas with strongly focused on-axis electron cyclotron heating (ECH) in LHD.

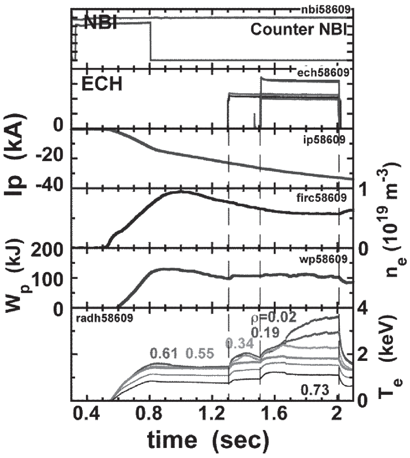

Fig. 1: Time evolution of some plasma parameters for counter-NBI plasma with ECH. Figures show NBI pulse, ECH pulse forms, plasma current I_p, line-averaged electron density n_e, plasma stored energy W_p and electron temperature by ECE (normalized radial position is indicated in the figure) from top to bottom.

Figure 1 shows a time evolution of some plasma parameters. A target plasma was initiated by co- and counter-NBI at first, then co-NBI pulse was switched off at $t = 0.8$ s while counter-NBI pulse was extended to $t = 2.1$ s. ECH power was injected from $t = 1.3$ s and from $t = 1.5$ s stepwisely. A plasma current in the counter direction continued to increase up to the end of the NBI pulse. As shown in T_e measured by ECE, a transition to high-T_e in the core region is obviously noticed at $t = 1.67$ s, when a rapid increase of core temperature and a little step-down of temperature in outer region ($\rho > 0.34$) occurred almost simultaneously. The inversion radius of the temperature change is about $\rho \simeq 0.3$.

The transition dynamics of the core temperature is analyzed by the time evolution of electron heat flux changes based on the data from ECE. During ECH pulse, ECH power is assumed to be constant. Ray tracing calculation shows that it is absorbed within $\rho \lesssim 0.2$. Then variation of an electron heat flux through a given normalized radius, ρ, and at time, t, will be given by a following equation outside of the ECH deposition layer.

$$\delta Q_e(\rho,t) \propto -\frac{1}{\rho}\int_0^{\rho}\left(\frac{3}{2}\right)\frac{\partial}{\partial t}\left\{n_e(\rho',t)T_e(\rho',t)\right\}\rho' d\rho' \qquad (1)$$

This corresponds to a time derivative of the total kinetic energy stored within a given radius ρ. Using temperature data measured by ECE and density data by FIR interferometer, temporal and spatial variation of δQ_e can be calculated. Difference of in- and out-flux through a thin layer $2\Delta\rho$ between $\rho - \Delta\rho$ and $\rho + \Delta\rho$ was calculated and defined as $\Delta\delta Q_e(\rho, t)$.

The values, $\Delta\delta Q_e(\rho, t)$, are calculated for the high-T_e transition shot described previously. In these analyses $\Delta\rho$ was selected to be 0.01. Difference between in- and out-heat fluxes at ρ is plotted as a function of time for the shot of the high-T_e transition in Fig. 2. Electron temperature is gradually increasing after on-timing of the second ECH pulse ($t = 1.5$ s), keeping a flat profile in the core region. From about 20 ms before a jump of core electron temperature at $t \sim 1.67s$, the value $\Delta\delta Q_e$ is increasing gradually between $\rho = 0.25$ and 0.45 (from $t = 1.65$ s to 1.67 s). More precisely, the slow decrease of temperature between $\rho = 0.3$ and 0.55 is observed. This fact implies that a recovering of confinement has been already begining around the central part of the plasma from $t = 1.65$ s gradually. Then abrupt dip of $\Delta\delta Q_e$ up to $\rho \sim 0.3$ and its increase at $\rho > 0.45$ can be noticed. It is suggested that a kind of transport barrier of electron heat transport was established at $\rho \sim 0.3$ at this moment and that the confinement of the electron energy was improved within $\rho \sim 0.3$.

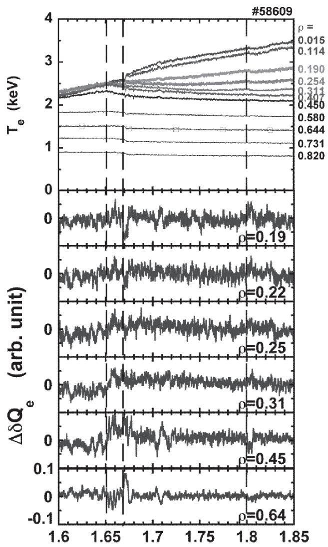

Fig. 2: Time evolution of T_e and difference of in- and out-flux of heat $\Delta\delta Q_e$ during high-T_e transition (shot#58609) for expanded time region from $t = 1.6$ s to $t = 1.85$ s. Normalized radial position ρ for flux difference is indicated in the figure, $\rho = 0.19, 0.22, 0.25, 0.31, 0.45, 0.64$, from top to bottom.