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§11. Complete Detachment of e-ITB Plasmas

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Complete detachment of plasmas with the electron Internal Transport Barrier (e-ITB) has been achieved for the first time in LHD in the 17th campaign experiment. Complete detachment is one of the possible scenarios to mitigate the high heat load on the divertor tiles in future fusion reactors. It takes place when the edge density exceeds the Sudo density limit and the hot plasma boundary shrinks [1]. The energy confinement often becomes deteriorated, however, during complete detachment. This occurs presumably due to the shallow penetration of the neutral beams (NB), which is mainly used in the experiments. In LHD, the heat deposition profile strongly affects the energy confinement [2]. Therefore, it is expected that good confinement will be maintained if central heating is applied during complete detachment. This has been realized using the electron cyclotron heating (ECH).

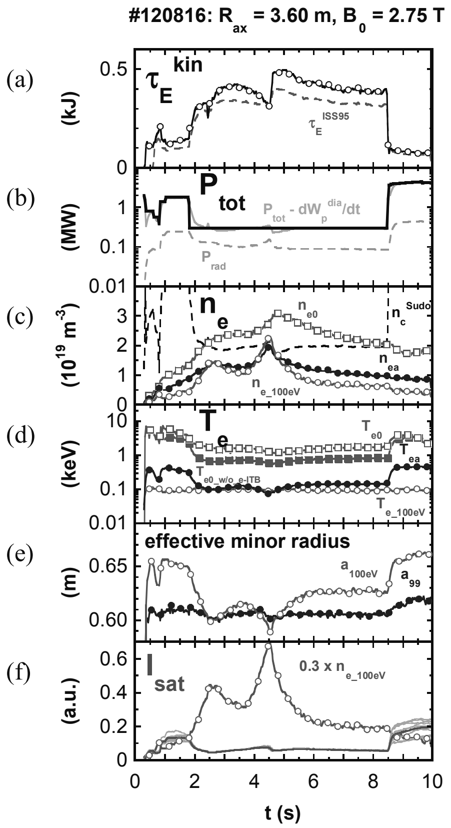

Fig. 1. Waveforms in a complete detachment discharge, where (a) the kinetic energy confinement time, τ_E^{kin}, and the prediction of ISS95, τ_E^{ISS95}, (b) the total heating power, P_{tot}, and the radiation loss, P_{rad}, (c) the central electron density, n_{e0}, the Sudo density limit, n_c^{Sudo}, the edge electron densities of n_{ea} at a_{99} and n_{e_100eV} at a_{100eV}, (d) the central electron temperature, T_{e0}, the central electron temperature extrapolated from the temperature profile outside of $r_{eff}/a_{99} > 0.6$, $T_{e0\_w/o/e\text{-}ITB}$, the edge electron temperatures of T_{ea} at a_{99} and T_{e_100eV} at a_{100eV}, (e) the effective minor radius defined by the position inside which 99 % of the plasma kinetic energy is confined, a_{99}, and the averaged radial position of $T_e \sim$ 100 eV, a_{100eV}, and (f) the averaged ion saturation current measured on the divertor tiles at various toroidal/poloidal positions, I_{sat}, and 0.3 n_{e_100eV}, are shown from top to bottom.

To achieve complete detachment at the density well below the ECH cutoff density, the heating power of ECH was reduced from ~2 MW to ~0.3 MW in the discharge shown in Fig. 1. Then, from ~2 to ~8 s, the hot plasma boundary, a_{100eV}, measured by the radial position where the temperature is ~100 eV shrinks to a_{99}, which is considered to be near the last-closed-flux-surface (Fig. 1(e)), and the divertor particle flux measured by the ion saturation current, I_{sat}, decreases at all of the divertor tiles (Fig. 1(f)). This is the complete detachment. As long as the plasma boundary is fixed, I_{sat} is proportional to the edge density, n_{e_100eV}, at a_{100eV} [1]. From this point of view, I_{sat} is reduced to less than 1/4 of the expected value of 0.3 n_{e_100eV} in Fig. 1(f) during ~2 to ~8 s.

The electron temperature profile was strongly peaked at the center showing the existence of e-ITB during complete detachment, as shown in Fig. 2. Formation of e-ITB is the clear evidence of central heating by ECH. As a result, the energy confinement was not deteriorated and kept ~1.2 times the ISS95 prediction even during complete detachment (see Fig. 1(a)). This is what expected.

1) J. Miyazawa, et al., Nucl. Fusion **46** (2006) 532.
2) J. Miyazawa, et al., Nucl. Fusion **52** (2012) 123007.

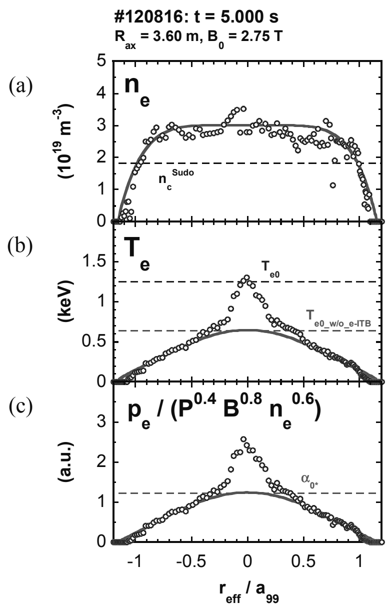

Fig. 2. Radial profiles of (a) the electron density, $n_e(\rho)$, (b) the electron temperature, $T_e(\rho)$, and (c) the gyro-Bohm normalized electron pressure profile, $p_e(r_{eff}/a_{99})$ / $(P_{tot}^{0.4} B_0^{0.8} n_e(\rho)^{0.6})$, where $\rho = r_{eff}/a_{99}$. Fitting curves are obtained by using the data in the outside region of $0.6 < (r_{eff}/a_{99}) < 1.0$, which gives $T_{e0\_w/o\_e\text{-}ITB}$ in (b).