§4. Dynamics of Ion Internal Transport Barrier in LHD

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The ITB formation, which is characterized by the abrupt appearance of large gradient region (ITB region) of temperature interior of the plasma, has been observed both in electron temperature (T_e) and ion temperature (T_i) transport in LHD plasmas. Although the mechanism of turbulence suppression and the reduction of thermal diffusivity can be explained by the ExB shear, the mechanism determining the magnitude and size of ITB (magnitude of the maximum T_i gradient and region of large T_i gradient) is not well understood.

The ITB plasma appears after the injection of negative neutral beams injection (N-NBI) with high energy at t = 0.9s to the relatively low density hydrogen NBI plasma sustained by positive neutral beam injection (P-NBI) with low energy in LHD. The radial profile and time evolution are measured with the charge exchange spectroscopy using the charge exchange line of the intrinsic carbon impurity. As seen in Fig.1, the T_i gradients are identical at various radii (ρ = 0.26, 0.44, 0.85). The T_i gradient at ρ = 0.44 gradually increases and that at ρ = 0.26 also increases 0.2sec after the additional heating by N-NBI (at t= 0.9sec). As indicated by the dash lines, the T_i gradients saturate in the low level when there is no ITB formation. During the formation of ITB, the increase of T_i gradient is mild (by a factor of 3) but the ITB region expands towards plasma core and becomes wide. The formation of ITB in the LHD plasma is characterized by the expanding ITB to the plasma center, which is in contrast to that the ITBs in tokamaks are localized at the narrow region of the plasma.

Simultaneous achievement of high T_i and low concentration of impurity is crucial for the high fusion triple product, because the impurity causes dilution of fueling particle. Since the particle diffusion in the plasma with ITB is relatively low because of the suppression of the turbulence, the sign of the convection, which appears as an off-diagonal term of the transport matrix, becomes important in the ITB plasma. The radial profiles of carbon density, n_C, is evaluated from the intensity of charge exchange line measured. As seen in Fig.2, n_C start to decrease due to an outward convection in the wide region of ρ = 0.25–0.75 and the radial profile of n_C becomes hollow during the ITB phase. The radial profile of n_C becomes extremely hollow "impurity hole" when the T_i gradient is large. No outward convection is predicted in the neoclassical impurity transport in LHD because of the negative radial electric field predicted in the ITB plasma, where the T_i is much larger than the T_e by a factor of two. The outward convection of the impurity transport in the ITB plasma is considered to be beneficial for the fusion relevant plasma in future.

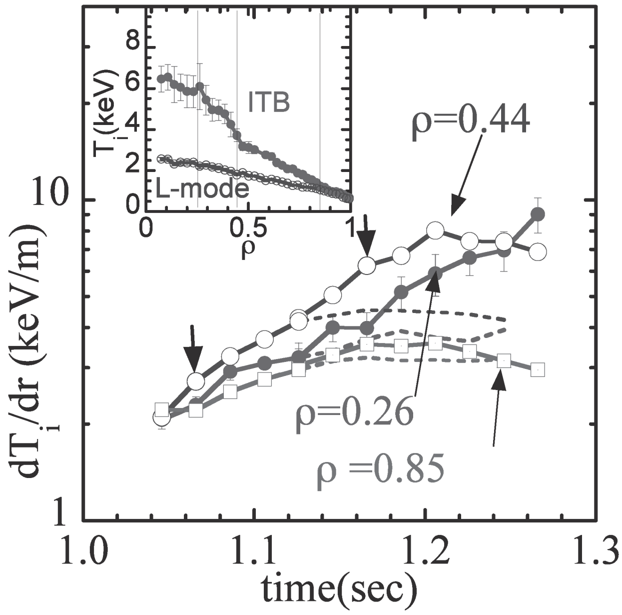

Fig.1 *Time evolution of ion temperature (T_i) gradient during the formation of internal transport barrier (ITB). Radial profiles of T_i in the L-mode and ITB phase (as indicated by arrows in the time evolution of dTi/dr) are also plotted and lines represent the location of dTi/dr traces. The dashed lines are time evolution of T_i gradient in L-mode as a reference. The region of large T_i gradient expands toward plasma core (ρ =0.44 → 0.26).*

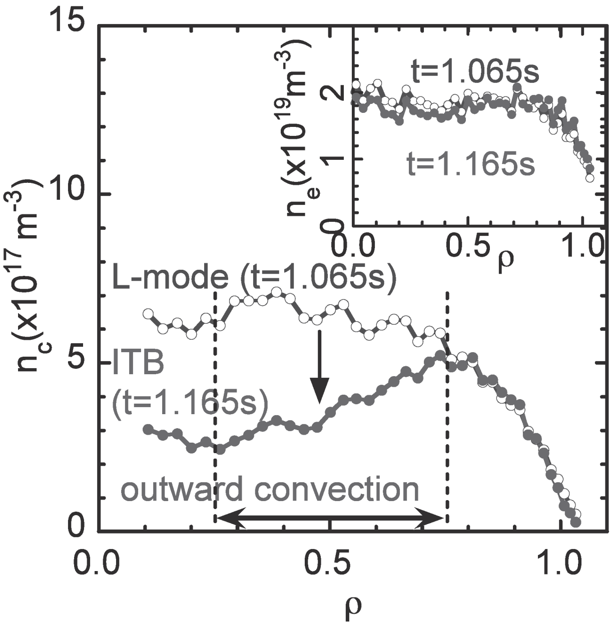

Fig.2. *Radial profiles of electron density and carbon density (n_C) in the L-mode and ITB phase (indicated by arrows in the time evolution of dTi/dr in Fig.1). Associated with the formation of ITB, a strong outward convection makes n_C profile to be hollow.*