§1. Dynamic Behavior of Nonlocally-coupled Ion Transport in Toroidal Plasmas

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A better understanding of electron and ion heat transport in magnetically-confined toroidal plasmas is highly necessary to have good control over burning fusion plasmas, since the burning plasmas is highly autonomous. In the electron and ion heat transport of the magnetically-confined toroidal plasmas, turbulent transport is dominant, which causes so-called "anomalous" transport. Unfortunately, characteristics of the turbulence-driven anomalous heat transport are still less well understood, because it sometime exhibits incomprehensible phenomena beyond the standard diffusive paradigm. One of the best examples of such phenomena is that a core electron temperature T_e is abruptly increased in response to an edge cooling invoked by a pellet injection[1)] or an impurity gas puff[2)]. A reversal of cold pulse polarity clearly indicates that this phenomenon is not a result of propagation of change in some physical quantities (even beyond a diffusive time-scale), but that of nonlocal coupling of the transport. Recent LHD experiments show further good examples of nonlocal coupling in ion transport.

As shown in Fig. 1(c), the core ion temperature T_i is abruptly increased in response to the edge perturbation invoked by a TESPEL (it can be considered as a very tiny plastic pellet) injection. Experimental conditions of this discharge are as follows: magnetic axis position of 3.55 m, toroidal magnetic field strength of 2.789 T, port-through power of negative-ion based NBI of 7.8 MW, port-through power of positive-ion based NBI of 3.0 MW, injected ECH power of 1.0 MW. The TESPEL deposition zone is estimated to be outside $\rho = 0.87$. In this case, the core T_e is also increased abruptly as well as the core T_i. Unfortunately, both T_i and T_e in the core region cannot be maintained at an elevated level and go down to a certain level that would be determined by the power deposition profile modified by the TESPEL injection. The time scale of the rise and fall of the core T_i seems to be similar to that of the core T_e. It should be noted here that the ablation and ionization of the TESPEL is driven mainly by the electron heat flux. Thus the T_i and its gradient in the edge region remain unchanged after the edge perturbation as shown in Fig. 1(c). Therefore this means that the change in the core T_i after the edge perturbation is a direct evidence of the nonlocal coupling of the ion heat transport. As can be seen in Fig. 2, when the electron density increases, the core T_i rise is no longer observed. On the contrary, the core T_i drop in response to the edge perturbation is observed. Furthermore, the nonlocal response of toroidal rotation velocity V_t to the edge perturbation is also observed. In some cases, the nonlocal response of T_i and V_t in the core region is observed independently. This indicates that the nonlocality of ion heat transport can be isolated from that of momentum transport.

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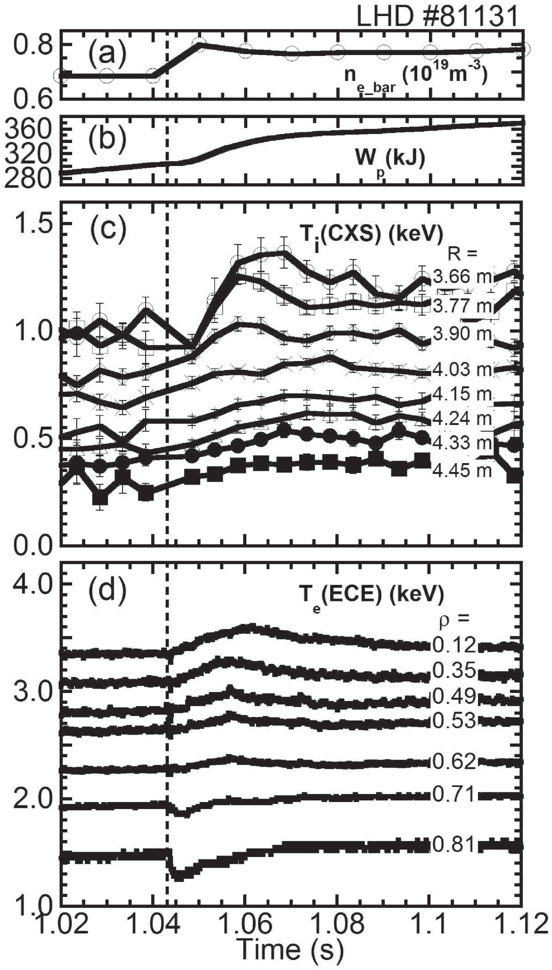

Fig. 1. Temporal evolution of (a) the line-averaged electron density, (b) the plasma stored energy measured by the diamagnetic flux loop, (c) the ion temperature measured using the charge exchange spectroscopy at different major radii and (d) the electron temperature measured with the ECE radiometer at different normalized minor radii. The vertical dashed line represents the time of the TESPEL injection.

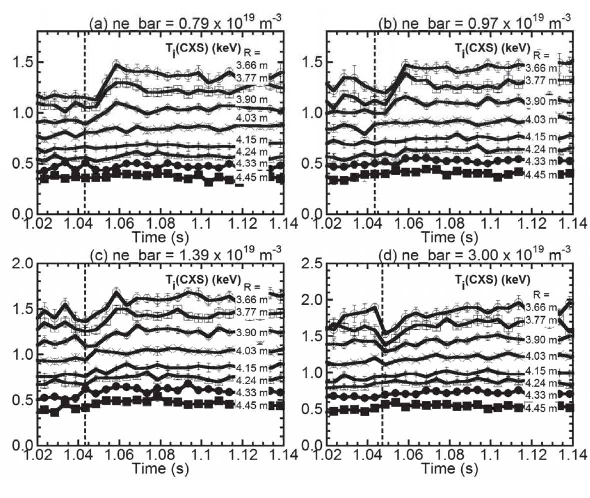

Fig. 2. Dependence of the T_i behavior in response to the edge perturbation on the line-averaged electron density. n_{e_bar} = (a) 0.79 x 10^{19} m^{-3}, (b) 0.97 x 10^{19} m^{-3}, (c) 1.39 x 10^{19} m^{-3} and (d) 3.00 x 10^{19} m^{-3}. Experimental conditions are the same as those of the discharge shown in Fig. 1.