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Transition of Heat and Momentum Transports
熱と運動量の輸送遷移現象

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Different toroidal rotation profiles were observed between co- and ctr-rotating plasmas with ion ITB in LHD. Transport analysis reveals the existence of spontaneous rotation which become large with increase of ion temperature gradient (growth of ion ITB). The differences of heat transport characteristics such as threshold heating power and saturation of temperature gradient, are observed, which seems to be attributable to rotation shear effect.

1. Introduction

Recently Non-local phenomena and off-diagonal term effects in transport matrix attract much attention in transport study of magnetically confined fusion plasmas. Because they often dominate the transport properties and are useful to control magnetohydrodynamics (MHD) stabilities. In particular, spontaneous rotation has been strongly studied in tokamak plasmas, and the empirical scaling law of spontaneous rotation was obtained for H-mode plasma [1]. However, the physical mechanism of spontaneous rotation and the effects on heat transport property are still open questions.

In this paper, heat and momentum transport observed in ion internal transport barrier (ion ITB) formation in the Large Helical Device (LHD) plasmas are presented. The spontaneous toroidal rotation and effects of rotation shear on the heat transport are discussed.

2. Ion ITB Plasmas in LHD

An ion ITB forms in LHD plasma heated by neutral beam injection (NBI) and has extended high-ion-temperature regime of helical plasma beyond 7 keV. The electrostatic potential measurement using a heavy ion beam probe (HIBP) showed a negative radial electric field (E_r) in the core region and no significant electric field sear was observed [2]. Numerical simulation studies suggest a zonal flow excitation in the core of ion ITB as a physical mechanism of ion ITB formation in helical plasmas [3]. The impurity transport in the ion ITB core in LHD is quite different from tokamak ITB plasmas and a significant outward convection of impurities forms a hollowed profile of impurities (Impurity Hole formation). The heavier impurities form the steeper hollowed profiles. The simultaneous realization of good heat confinement and poor impurity confinement is preferable for steady state operation of fusion burning plasmas [4-5].

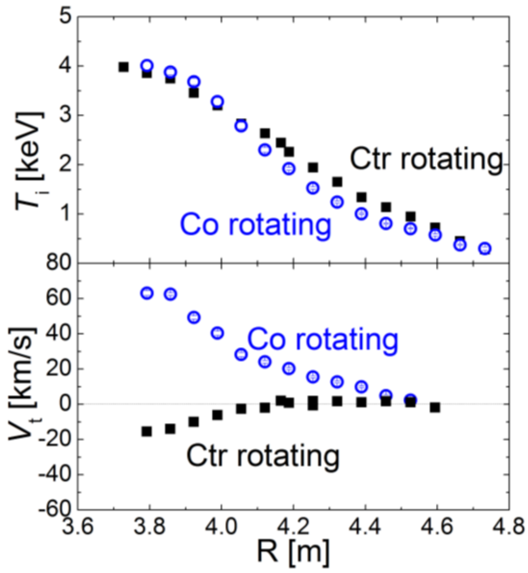

Fig. 1 Ion temperature and toroidal rotation profiles in the case of co-rotating (P_{nb_Co}=7.4MW, P_{nb_Ctr}=2.6MW, P_{nb_perp}=3.3MW and n_{e_bar}=1.5 x 10^{19} m^{-3}) and ctr-rotation plasmas (P_{nb_Co}=3.5MW, P_{nb_Ctr}=9.0MW, P_{nb_perp}=3.6MW and n_{e_bar}=1.6 x 10^{19} m).

3. Dependence on the direction of rotation

Figure 1 shows the profiles of ion temperature and toroidal rotation with ion ITB in the case of co- and ctr-rotating plasmas. The direction of toroidal rotation in the ion ITB core is consistent with external torque (tangential NBI). But the rotation profiles are significantly different between co- and ctr-rotations. The rotation shear of co-rotating plasma is larger than that of ctr-one. The ion temperature is slightly different between them, and the temperature gradient in co-rotating plasma is larger, implying that the even weak rotation shear may affects the heat transport.

In order to investigate the transport characteristics, the heat and momentum deposition profiles of tangential and perpendicular NBIs are evaluated by FIT code, and the heat and momentum flux at the normalized minor radius of (r_{eff}/a_{99})~0.3 was estimated. Figure 2 shows the flux v.s gradient relation of momentum transport in the transition phase from L-mode to ion ITB. The shear of co-rotating plasma increases in the ion ITB phase, while it of ctr-rotating one is suppressed. This indicates that the spontaneous rotation with the growth of ion temperature gradient (formation of ion ITB) is driven in the co-direction.

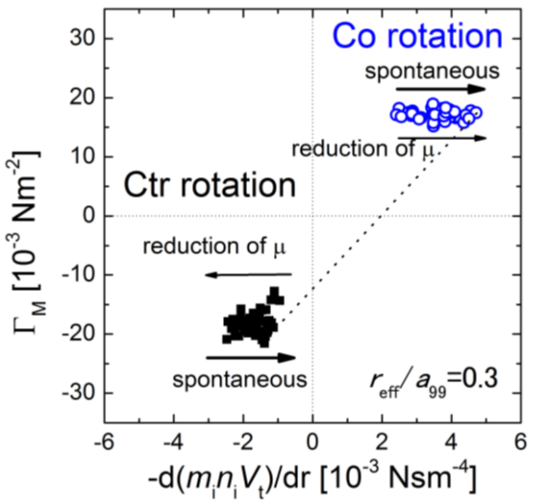

Fig. 2 Momentum transport flux as a function of gradient of momentum at the normalized minor radius of 0.3. The momentum flux and the gradient of momentum in the ctr-rotating plasma are negative values. For the comparison, the absolute values of them are plotted in this figure.

Figure 3 shows the normalized heat flux as a function of temperature gradient. The temperature gradient increases with heating power with similar slope between co- and ctr-rotating plasmas. However the threshold power for ion ITB transition seems to be different and higher heating power is required in the ctr-rotating plasma. The larger temperature gradient is obtained in the co-rotating plasmas with lower heating power.

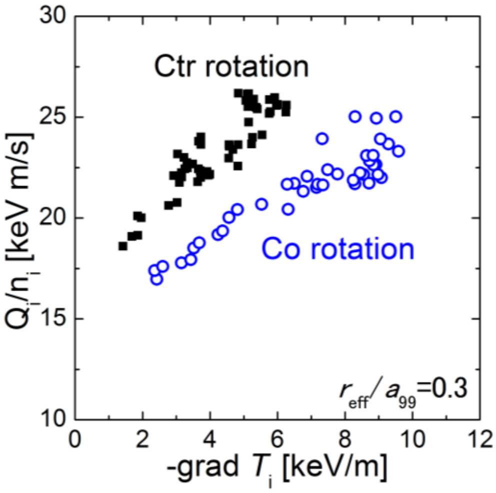

Fig. 3 Flux-gradient relation of ion heat transport at normalized minor radius of 0.3

4. Discussions and Conclusions

Non-linear flux-gradient relations are clearly found in momentum and heat transport of ion ITB plasmas. The comparison between co- and ctr-rotating plasmas reveals the existence of spontaneous rotation driven in the co-direction with increase of ion temperature gradient (growth of ion ITB) and better heat confinement characteristics (larger ion temperature gradient and lower threshold power) in the co-rotating plasmas. It is interesting from viewpoint of comparison with transport suppression by rotation shear discussed as a tokamak ITB mechanism [6]. In order to understand the mechanism of ion ITB in helical plasmas, further investigations and detailed analyses are necessary in both experimental and theoretical fields.

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References

[1] J. Rice, et al.,: Nucl. Fusion **47** (2007) 1618.
[2] K. Nagaoka, et al.,: Nucl. Fusion **51** (2011) 083022.
[3] M. Nunami, et al: Plasma Fusion Res. **6** (2011) 1403001.
[4] M. Yoshinuma, el al.,: Nucl. Fusion **49** (2009) 062002.
[5] K. Ida, el al.,: Phys. Plasmas **16** (2009) 056111.
[6] H. Jhang,: 1st Asia Pacific Transport Working Group, PLI-3, Toki, Japan, 2011.