§1. Formation of IronImpurity Transport Barrier in LHD Plasmas with Hollow Density Profile

Morita, S., Huang, X.L., Oishi, T., Murakami, I., Goto, M., Zhang, H.M., Liu, Y. (SOKENDAI)

Recently, the impurity transport has been extensively studied to control the impurity accumulation of tungsten in tokamaks. In the Large Helical Device (LHD), on the other hand, the n_e profile can exhibit a variety of distributions of a peaked, flat or hollow shape. If the impurity transport of heavy impurities is strongly affected by the n_e profile, the impurity control is possible in the plasma core. Therefore, it is of great importance to investigate the radial transport of heavy impurity in LHD.

Radial profiles of line emissions of Fe^{16+} through Fe^{23+} ions have been simultaneously observed in the n = 3–2 L_α transition array using a space-resolved extreme ultraviolet spectrometer.[1] Based on the profile analysis, the radial profile of total iron density (N_{Fe} (ρ)) is then calculated for peaked and hollow n_e profiles in discharges with magnetic axis R_{ax} = 3.6 m and magnetic field B_t = 2.75 T. The N_{Fe} in the plasma center (ρ = 0) and near the edge (ρ = 0.85) is also evaluated as function of central electron density, as displayed in Fig. 1. The N_{Fe} (ρ = 0) at the peaked n_e profile is at least one order of magnitude higher than that at the hollow n_e profile over a wide range of electron density. Since the edge iron density does not vary so much between the two cases, the iron influx entering the plasma core also has a similar value in two cases. Therefore, the present result strongly suggests the radial transport of iron ions is entirely different between the two n_e profiles.

A one-dimensional impurity transport code is employed to simulate the iron density profile as a function of time with transport coefficients as an input parameter.[2] The transport analysis is performed at quasi-stationary discharge phase in which the background plasma changes slowly and is not significantly perturbed by the Fe pellet. The emission intensity profile evaluated from the simulated time-dependent iron density profile is used to minimize the error (χ^2) by comparing with the measured emission intensity profile. The minimization process of χ^2 through an iterative analysis determines the transport coefficients. The convective velocity V is assumed to be proportional to the ion charge q, while the diffusion coefficient D does not depend on q.[3] It should be noted here that the iron transport can be analyzed without any assumption on the radial structure of transport coefficients because the Fe L_α transitions are sufficiently distributed in a wide radial range.

In peaked and hollow n_e profiles as plotted in Fig. 2(a), the transport coefficients are evaluated as shown in Fig. 2(b). The V in the figure represents the convective velocity averaged by eight ionization stages of Fe^{16+} through Fe^{23+}. The D profile is very similar between peaked and hollow n_e profiles, while the D value gradually increases toward the plasma edge from the center. On the other hand, the V profile is entirely different between the two cases. In the peaked n_e profile, the V is negative, i.e. inward, and increases from the plasma center to the edge. This indicates the impurity accumulation easily occurs with a peaked n_e profile. In the hollow n_e profile, an outward V is obviously observed in the core region of $\rho \le 0.8$. The V changes from outward to inward near the edge where the n_e gradient changes the sign from positive to negative. The iron ion is pushed back outwards near ρ = 0.8 and concentrated near the edge when the n_e profile is hollow. The impurity transport barrier is thus formed by this quick change in the radial structure of V. As a result, the large difference in the n_{Fe} (ρ = 0) between peaked and hollow n_e can be well explained by the significant difference in the radial V profile.

The present result demonstrates that the control of heavy impurities is possible in LHD by controlling the n_e profile. Hollow n_e profiles are usually observed in high-temperature and low-collision plasmas with high NBI power input. Since the neoclassical theory predicts that the convective velocity increases with ion charge, the outward convection can work further favorably to heavier impurities such as tungsten, suggesting a better impurity control.

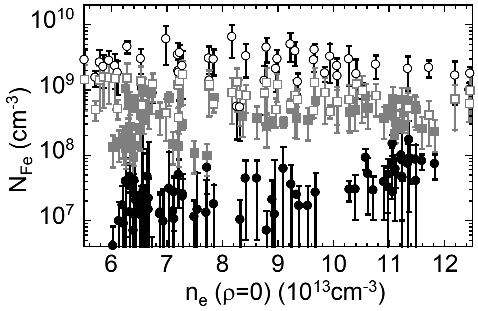

Fig. 1. Iron density at ρ=0 and 0.85 against central electron density for peaked (open circles and open squares) and hollow (solid circles and solid squares) n_e profiles, respectively.

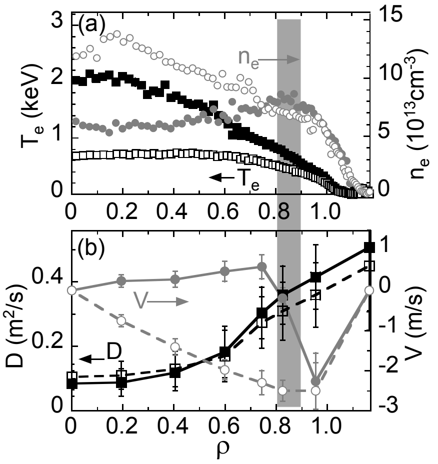

Fig. 2. Radial profiles of (a) T_e (squares) and n_e (circles) and (b) diffusion coefficient (squares) and convective velocity (circles) for peaked (open symbols) and hollow (solid symbols) ne profiles. Hatched area denotes radial region of the impurity transport barrier.

1) Huang, X.L. et al., Rev. Sci. Instrum. **85** (2014) 043511.
2) Morita, S. et al., Plasma Sci. Technol. **8** (2006) 55.
3) Nozato, H. et al., Phys. Plasma **11** (2004) 1920.