Observations of Impurity Hole on LHD

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Abstract

Impurity hole, which is an extremely hollow profile of carbon impurity, is observed associated with increase of ion temperature gradient in the Large Helical Device. Neoclassical prediction can not explain the outward convection which causes the hollow profile. The dependence on the magnetic axis position of the convection velocity in the impurity hole is evaluated. It is suggested that the impurity hole becomes strong as the magnetic axis is shifted outward.

1. Introduction

Simultaneous achievement of improved energy confinement and low impurity confinement is one of the crucial issues to realize the plasma relevant to nuclear fusion because impurities cause reduction of the fusion power density by enhancing the cooling of the plasma with radiation and also by diluting the hydrogen fuel. Impurities tend to accumulate in the plasma with an improved confinement mode such as H-mode and internal transport barriers (ITB) in tokamaks. Although impurity accumulation can be avoided in the ELMy H-mode discharges, impurity accumulation is still a problem in the discharges of the ELM-free H-mode and the discharges with an internal transport barrier. On the other hand, temperature screening effect due to an ion temperature gradient is expected in tokamaks and the outward convection of impurities was confirmed in the improved confinement plasma with a weak density gradient and a strong ion temperature gradient on DIII-D [1]. Impurity accumulation can be avoided by density profile control with an intensive gas puff, and high energy and low impurity confinement times are demonstrated in high density H-mode (HDH) plasma in the Wendelstein 7-AS stellarator [2]. Radial electric field is strongly affected to the impurity transport in non-axisymmetric system. The impurity convection can be outward and the impurity density can be hollow due to the positive radial electric field in the electron-ITB plasmas, where the electron temperature is much higher than the ion temperature. Although inward convection of impurities is expected from neoclassical theory in the plasma with a high ion temperature gradient because of the negative radial electric field, extremely hollow impurity profiles due to an outward convection is observed in the plasma with a steep gradient of ion temperature is observed in LHD.

2. High Ti discharge in LHD

LHD is a heliotron-type device equipped with three high energy beam lines that have the beam energy of 180keV with negative ion sources (N-NBI) and a low energy beam line that has the beam energy of 40 keV with positive ion sources (P-NBI). The high energy beams have the advantage in the electron heating, and these are injected to the plasma tangentially. The low energy beam has the advantage in the ion heating and also in the charge exchange spectroscopy and injected to the plasma perpendicularly. The ion temperature, toroidal flow velocity, poloidal flow velocity, and intensity of the charge exchange emission from carbon impurity (CVI, λ=529.05 nm) are measured with the charge exchange spectroscopy using the P-NBI as a probe beam. In order to subtract the background emission, which is cold component from the plasma periphery, the beam is modulated on and off. The radial electric field can be derived from the poloidal flow velocity. Carbon density can be derived from the intensity of the emission from carbon impurity by charge exchange between the fully ionized carbon in plasmas and the neutral beam.

Figures 1 (a) and (b) show the time evolution and radial profile of the ion and electron temperature in the plasma with the magnetic axis R_{ax}=3.6m, the magnetic field strength B=-2.75T, the coil pitch parameter γ=1.254, and the canceling rate of the quadrupole filed B_q=100\%., respectively. Steep gradient of ion temperature is produced at the mid-radii, and the ion temperature becomes higher than the electron temperature at the center of the plasma.
The higher ion temperature plasma is produced by injection of N-NBI into the plasma sustained by the P-NBI. After the N-NBI injection, the ion temperature profile is changed from the hill shape, which is moderately increased toward the center, to the bell shape, which is a peaked profile with a steep gradient at the middle of the plasma radii, while the electron temperature is moderately increased toward the center as shown in Fig.1 (b). Figures 1 (c) shows the profile of the intensity of charge exchange emission from carbon impurity. The intensity of carbon impurity at the center of the plasma decreases as the ion temperature increases, and it becomes one digit smaller than that before the ion temperature rise, while the intensity changes small at the edge as shown in Fig.1 (c). This observation shows that the hollow profile of the carbon density is produced in the high ion temperature plasma with steep gradient of the ion temperature. We denote that the hollow profile observed with the steep gradient of ion temperature as “Impurity Hole”.

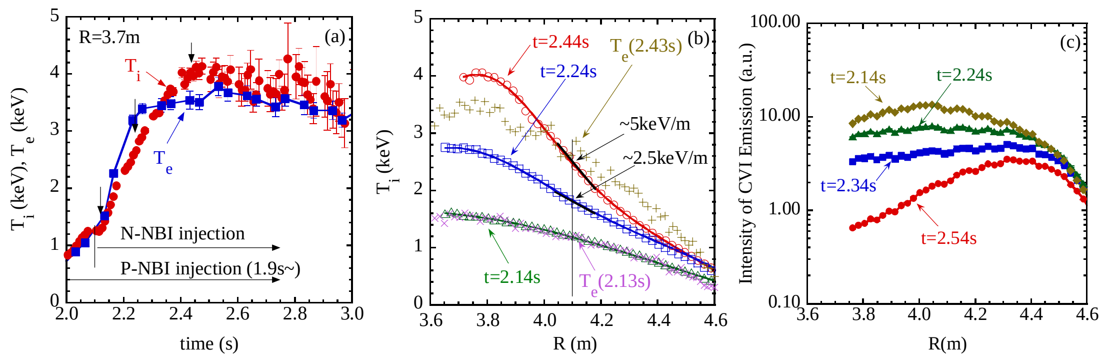

Fig.1 (a) Time evolutions of electron and ion temperature. (b) Radial profiles of ion and electron temperature. (c) Radial profiles of charge exchange emission from carbon impurity.

3. Dependence on magnetic axis position of impurity hole

Position of magnetic axis is one of control parameters which changes helical ripples, and it affects radial electric field and confinement. The radial electric filed shear changes associated with the changing the profile of the helical ripples controlled by the changing the magnetic axis has demonstrated [4]. Helical ripple sharply increases at the plasma edge and the electron root region is localized near the plasma edge in the inward shift case, while helical ripple gradually increases towards the plasma edge and the electron root regime extends to plasma core. The dependence on the magnetic axis position of density profiles has been clearly observed in LHD, and the peaking factor of the density profile decreases with increases of the magnetic axes shift [5]. The change of the magnetic axis or helical ripples affects not only the neoclassical transport but also the anomalous transport. There is the simulation result that turbulent transport is reduced with enhancing zonal-flow generation in the plasma with inward shifted configuration

[6]. Thus the dependence on the magnetic axis is expected to be exists in many observations in helical systems.

Figure 2 shows the dependence on the ion temperature gradient of the convection velocity of carbon impurity at ρ=0.5 in the plasma with magnetic axis changed. The magnitude of convection velocity increases towards the outward (positive) as the ion temperature gradient is increased. The change of the convection velocity is more sensitive to the change of the ion temperature gradient in the plasma with outward shifted configuration than in the plasma with inward shifted configuration.

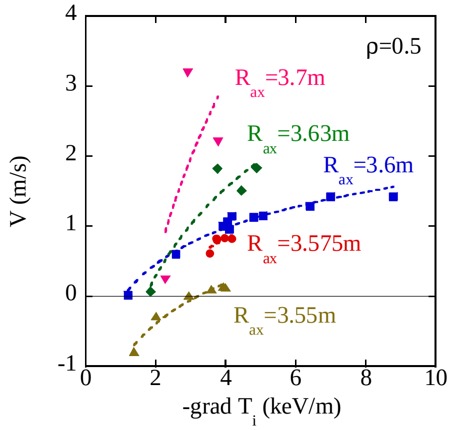

Fig.2 Dependence on ion temperature gradient of convection velocity of carbon impurity in the plasma with magnetic axis changed.

4. Summary

Extremely hollow profile of carbon impurity is observed in the plasma with the steep gradient of the ion temperature. Transport analysis shows low diffusion coefficients of both carbon and bulk ions in the plasma core, and small positive convection of bulk ions and much larger positive convection of the carbon impurity. The outward flow of carbon impurity is considered to be due to the ion temperature gradient and driven by the turbulence because the sign of the convection velocity is opposite to the neoclassical prediction. Dependence of convection velocity on the magnetic axis position is clearly observed in the plasma with ion temperature gradient. It is suggested that the impurity hole becomes strong as the magnetic axis is shifted outward.

Reference

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