II. Research Activities

1. Large Helical Device (LHD) Project

1-1. LHD Experiment

(1) Overview of LHD Experiment

During 11th campaign of the LHD experiment, we have made significant progress in various physics research areas, in particular achievement of hot ion temperature plasma, study of SDC plasma (super dense core plasma mode) in the extended parameter space.

The high-ion-temperature regime has been further extended, achieving the ion temperature (T_i) of 6.8 keV in hydrogen-main plasma with the electron density (n_{e_bar}) of about 2×10^{19} m^{-3} (Fig.1). Figure 1 summarizes the progress of high-T_i experiments in the last two campaigns, showing that the progress was made around n_{e_bar}~1-2×10^{19} m^{-3}.

The effective increase of the injection power from the perpendicular NBI (#4) through the increase of the ON-duration (CXS measurement requires the modulation (ON-OFF) to acquire the background signals) works to extend the record-T_i value. Bundling the CXS fibers for signal enhancement from the core region to overcome the difficulty in measuring T_i even with "impurity hole", also extends the measurable range of T_i.

High T_i phase is achieved several hundred milliseconds after the injection of NBI-#4 to the base plasma heated by tangential NBIs (#1-#3), and could be sustained for a few times longer than the energy confinement time. After this high-T_i phase, T_i rapidly decreases. Understanding the mechanism of this transient behavior has been pursued to prolong the high-T_i phase.

The improvement of ion heat confinement has been recognized. The ion temperature gradient in the core region in NBI#1-#4-heated (tangential+perpendicular beams) phase exhibits more favorable dependence on the ion heating power normalized by the density, compared to L-mode type dependence observed in NBI#1-#3 phase (only tangential beams). The power threshold is also seen for the improvement of ion heat confinement.

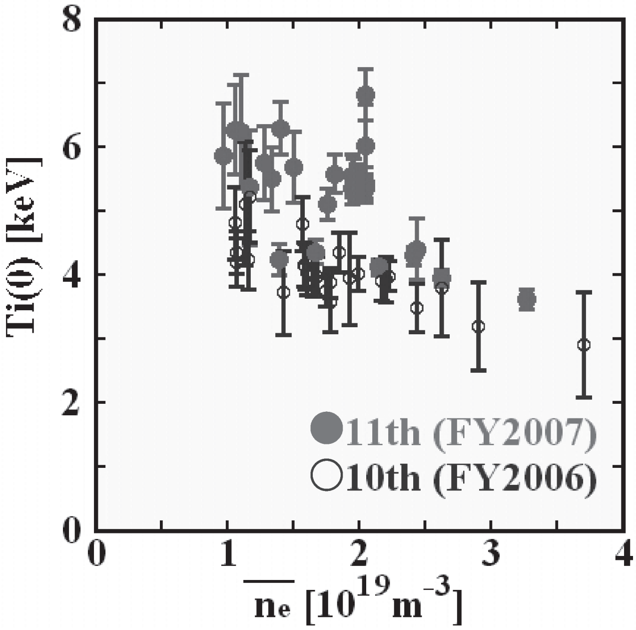

Fig.1 T_i at the plasma center (measured by charge exchange spectroscopy, CXS) as a function of line-averaged density. The closed circles are data obtained in 11th campaign (FY 2007) and open one in 10th campaign (FY 2006).

Neoclassical transport analyses have shown that the anticipated ambipolar radial electric field (negative, ion root) can avoid appearance of the ripple transport scaling (neoclassical heat diffusivity $\chi_{i,NC}$~$T^{4.5}$). Power balance analyses have also revealed the favorable power or temperature dependence such as $\partial\chi_i/\partial P_i<0$ and $\partial\chi_i/\partial T_i<0$, which clearly indicate the improved ion heat confinement.

In the large helical device (LHD), an extreme hollow profile of carbon impurity has been observed in the high ion temperature plasma with a single carbon pellet. We have estimated the diffusion and convection of both the carbon and hydrogen. Figure 2(a) and (b) show the diffusion coefficient D and the convection velocity V, respectively, of the carbon and the hydrogen. The diffusion coefficient of hydrogen is larger than that of carbon while the shapes of the profile are almost same as shown in Fig. 2 (a). The convection velocity of the

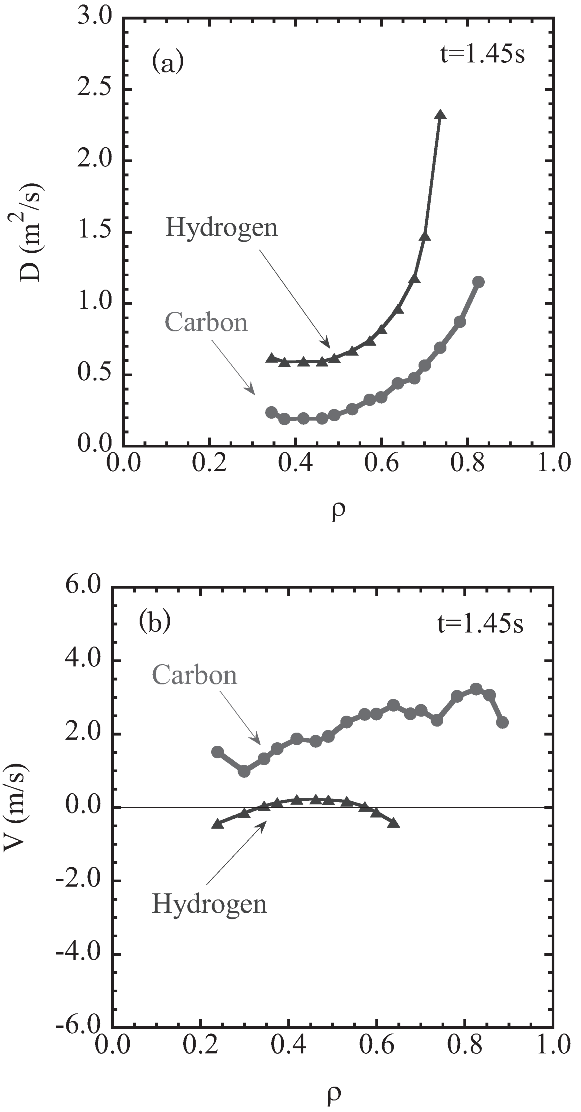

Fig. 2. (a) The profiles of diffusion coefficient of the carbon (circle) and hydrogen (triangle). (b) The profiles of convection velocity of the carbon (circle) and hydrogen (triangle).

carbon is positive, which means outward flow, while the convection velocity of the hydrogen is almost zero in the mid-radius of the plasma as shown in Fig. 2 (b). The outward flow is considered to be a key for the formation of the strong hollow profile of the carbon, and the hollow profile is not observed in the profiles of the hydrogen. The impurity hole grows up and sustains with the small diffusion and the outward convection.

The SDC plasma mode we observe in the LHD is very attractive scenario in achieving the ignition in the helical devices. Super dense core plasma (~5.0×10^{21} m^{-3}) allows relatively low temperature operation (~7keV) for the ignition. We study this mode experimentally in more detail.

Intensive pellet fueling experiments have been performed to extend an operational space of high density plasmas. Central fueling by pellet injection is essential for formation of the SDC plasma, which easily appears in the outer shifted magnetic configuration (4.0m > R_{ax} > 3.75 m). The attainable central plasma density becomes as high as 1.0×10^{21} m^{-3}.

We find that the central temperature is not less than 0.3 keV independently of the preset magnetic axis, neutral beam heating power and central density. Under the temperature below 0.3 keV, injected pellets pass through the plasma cross section without ablation and the central electron density shows no effective increase with subsequent pellet injections.

A neutral beam deposit calculation indicates that central heat deposition become to be inhibited as the density increase in general, and this tendency is particularly true for inward shifted configuration. This result suggest that the minimum temperature which is required to ablate the solid hydrogen pellet is not kept due to lack of an effective central heating power in inner shifted configuration, and therefore high density operation is not available. The experimental fact that the attainable density decrease when the neutral beam heating power is reduced can be also explained by the lack of effective central heating power.

A high central beta plasma is obtained with SDC plasma, i.e., peaked pressure profile. However, the increase of β_O is limited by the so-called core density collapse (CDC) events, which is an abrupt event where the core density is collapsed within 1 ms. The attainable central density is directly related to the central heating power, and if the central heating is available even in the inner shifted magnetic configuration in which excellent global confinement property is provided, further extension of the operational space are expected.

The highest β_O (#80586, shown in Fig.3) is obtained with R_{ax}^{vac} = 3.65m (B_t = 0.65T), which is so far the smallest value where the peaked pressure profile can be formed. Even with a higher toroidal magnetic field, the central beta (β_O = 9.9 %) is comparable to the value in the highest averaged-beta discharge (#69910, R_{ax}^{vac} = 3.6m and B_t = 0.425T) (Fig. 3). We continue the optimization of the configuration in order to get the higher value of the beta at the plasma core.

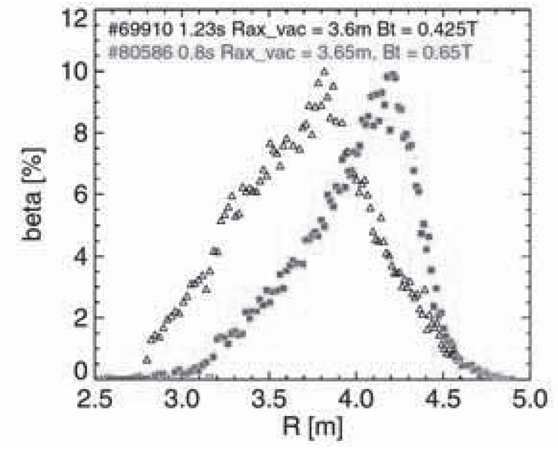

Fig.3: Comparison of the beta profile between an averaged-high-beta discharge (<β > ~ 4.8%) and a

(Komori, A.)