II. Research Activities

1. Large Helical Device (LHD) Project

1-1. LHD Experiment

(1) Overview of LHD Experiment

The 10th campaign of the LHD experiment has been executed successfully. We have made significant progress in three physics research areas, achievement of hot ion temperature plasma, exploration of SDC plasma (super dense core plasma mode) in the expanded parameter space and achievement of the average beta of 5.0%.

The production of high-ion-temperature hydrogen plasma was successfully demonstrated in the Large Helical Device (LHD) experiment (Fig.1). The ion temperature (T_i) exceeded 5 keV (the record high value of T_i in helical plasmas) at the plasma density (n_e) of 1.2×10^{19}m^{-3} and also achieved 3 keV at n_e~4×10^{19}m^{-3}. This achievement demonstrated the capability of high-ion-temperature plasma confinement in helical devices. The total power of neutral beams as much as 20 MW (3 parallel-injection and 1 perpendicular-injection) and ion cyclotron heating power of about 2 MW contributed to make this realize.

The radial profiles of the toroidal rotation (V_t) as well as T_i were measured by means of the charge exchange recombination spectroscopy (CXRS) with the toroidal-view. The CXRS measurement has clarified that high-T_i plasmas typically have large V_t (as large as several tens of km/s) at the core region accompanied by an increase of T_i gradient. This observation indicates that the ion heat confinement is improved in high-T_i discharges associated with the presence of a large V_t.

It is also interestingly observed that the emission intensity from carbon-impurity ions (for CXRS measurement) at the core region strongly drops as the core-T_i becomes higher. It implies that the carbon-impurity ions are expelled from the core region. This phenomenon has been dubbed as "impurity hole". This unique feature may provide the efficient knob to avoid the impurity accumulation in reactor-relevant helical plasmas.

We have also initiated the relevant transport analysis. The ions are in 1/ν regime for these high-T_i plasmas, and neoclassical (NC) ambipolar E_r is predicted to be negative (ion-root). This prediction indicates that the hollow impurity profile (usually anticipated from the positive E_r (electron-root)) must be due to effects beyond the NC transport theory. The theoretical study to clarify the role of large V_t for the improved ion heat confinement has also been performed from the viewpoint of plasma viscosity structure in three-dimensional magnetic configurations. It is anticipated that systematic theoretical study may provide fruitful experimental scenarios for pushing the T_i-record higher in LHD.

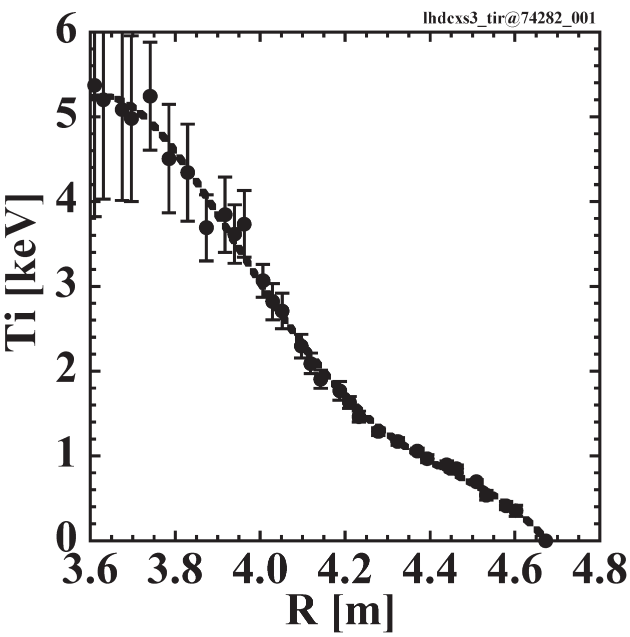

Fig.1 The T_i profile (measured by CXRS) in the highest T_i hydrogen-main plasma (#74282) obtained in the 10th-LHD experimental campaign.

An experimental study is performed to explore the operational space of a super dense core plasmas due to an internal diffusion barrier, which was originally found in pellet fueled high density discharges with the local island divertor configuration, in Large Helical Device (LHD). The internal diffusion barrier with steep gradient has been produced at an intrinsic helical divertor configuration in LHD by optimizing the pellet fueling and magnetic configuration.

Core fueling by multiple pellet injections is essential for the internal diffusion barrier formation. Nine-barrels in-situ pneumatic pipe-gun was employed to inject solid hydrogen pellets, which contain 1.5 - 2.0×10^{21} hydrogen atoms, at a velocity of ~1100 m/s every several 10 ms.

A global confinement property reach a maximum performance at an inward shifted magnetic configuration (R_{ax}= 3.65 m) which give a maximum plasma volume (Fig.2). The internal diffusion barrier, on the other hand, easily appears in the outward shifted magnetic configurations (R_{ax} > 3.75 m) in which magneto hydrodynamic stability properties are considered to be favorable. A central pressure of the super dense core plasma increase with density and the central pressure exceeds atmospheric pressure. The super dense core plasma is, therefore, characterized by very large Shafranov shift (Δ/a_{eff} ~ 1/2), even at high magnetic field (B_t> 2.54 T).

Maximum central density reaches 1×10^{21} m^{-3} just after pellet injection at R_{ax}= 3.9 m and above. Central pressure reach its greatest value at the neighborhood of R_{ax}= 3.85 m (Fig. 3). The maximum central pressure is limited by an core density collapse (CDC) event

Core density collapse (CDC) is a relaxation events observed in the SDC plasmas. When the magnetic axis exceeds about 4.1m and 4.0m at the horizontally and vertically elongated section, respectively, the CDC events happen. From the time evolution of the soft X-ray (SX) radiation intensity, the time scale of the events (typically 0.1-1 ms) is studied. Two stages are identified in the events, the pre-cursor phase and the rapid drop phase. The time scales become shorter when the core electron temperature increases. From the SX radiation profile, rapid movement towards outboard side just before the events is often observed. Magnetic reconnection from the movement is one possible scenario to explain this rapid loss.

The average beta of 4.8% has been obtained with increasing NBI power. With pellet injection, we have achieved the average beta of 5.0% , which is the target value in the conceptional design phase of the LHD.

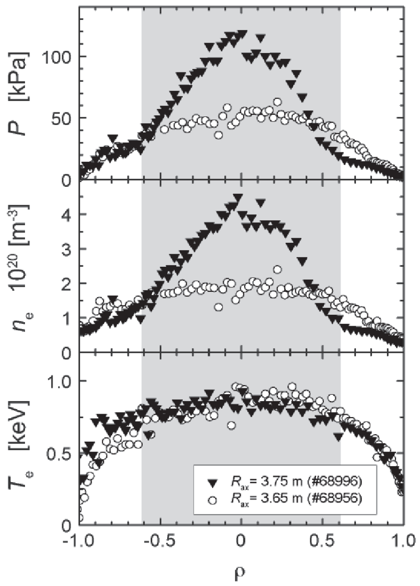

Fig. 2 Comparison of plasma profiles of the super dense core plasma due to an internal diffusion barrier (R_{ax}= 3.75 m) and normal discharge plasma (R_{ax}= 3.65 m).

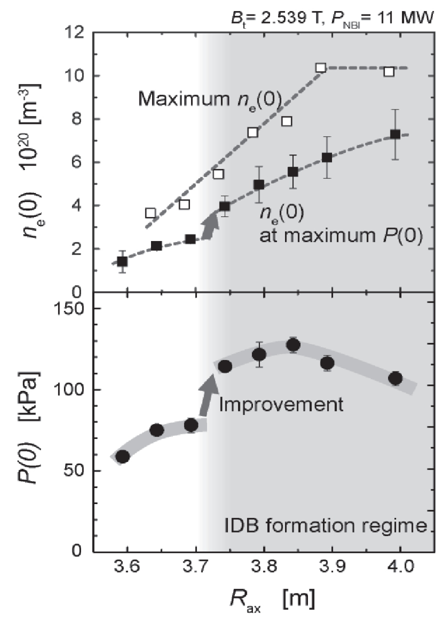

Fig. 3 Operational space of the super dense core plasmas due to Internal diffusion barrier.

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