II. Research Activities

1. Large Helical Device (LHD) Project

1-1. LHD Experiment

(1) Overview of LHD Experiment

The 12th experimental campaign of LHD experiment has been executed successfully in the Japanese fiscal year 2008. The LHD experiment group has advanced plasma parameters and deepened understanding of plasma physics. Diversified experimental proposals were managed in the framework of four major mission-oriented theme groups (high density and related confinement improvement, high β, steady state, and high ion temperature) and five physics oriented theme groups (core confinement physics, scrape-off layer and divertor physics including plasma material interaction, MHD, physics of energetic particles, wave physics). Integrated prospect of a helical fusion reactor as well as comprehensive understanding of toroidal plasmas, in particular in terms of 3-D effect, has been improved steadily by each progress.

The highlighted achievements in plasma parameters are high β (<β> of 5.1%), high ion temperature ($T_i(0)$ of 5.6 keV at $n_e(0)$ of $1.6 \times 10^{19} m^{-3}$), high density ($n_e(0)$ of $1.2 \times 10^{21} m^{-3}$), and store energy ($W_p$ of 1.64 MJ). Database in the high density and high beta regimes beyond tokamaks has been much improved and physical properties in these extended regimes have been studied in cooperation with advanced computation. A new pulsed power supply for poloidal coils has enabled control of the position of the magnetic axis during a discharge. Its fundamental function has been demonstrated in the high-β experiment and the boundary of violation of MHD stability has been explored experimentally in detail. The further progress in the β value is expected in the next experimental campaign by making full use of this scheme. In super high density regime characterized by an *Internal Diffusion Barrier* (IDB), compatibility of an IDB and detachment, and effect of Resonant Magnetic Perturbation (RMP) have been explored. The charge exchange recombination spectroscopy, which provides profiles of ion temperature and velocity, has been improved to cope with the phase with reduced carbon impurity. In result, documentation of *Impurity Hole*, which is impurity pump-out from the core accompanying the increase in ion temperature, has been advanced. Discovery that the carbon impurity is reduced to less than 0.3 % in the confinement improved phase with high ion temperature exceeding 5 keV is a critical epoch leading to resolution of a dilution issue in a fusion reactor. This important process coincides with spontaneous toroidal rotation and suggests a strong correlation between different physical quantities to generate off-diagonal transport. Heavy Ion Beam Probe (HIBP) can be cited for an example of advanced diagnostics, which has exhibited its performance in identification of bifurcation of radial electric field and the Geodestic Acoustic Mode (GAM) driven by energetic particles.

In order to investigate the edge stochasticity and its effect on particle and energy transport, an RMP was applied to the high density discharge. While edge electron density is dramatically suppressed by RMP, the central density can be increased to the same level as in the case without RMP. The suppression of edge density facilitates central heating by neutral beams and consequently the central temperature as well as the central pressure doubles. The RMP also helps access to detachment with keeping the property of an IDB.

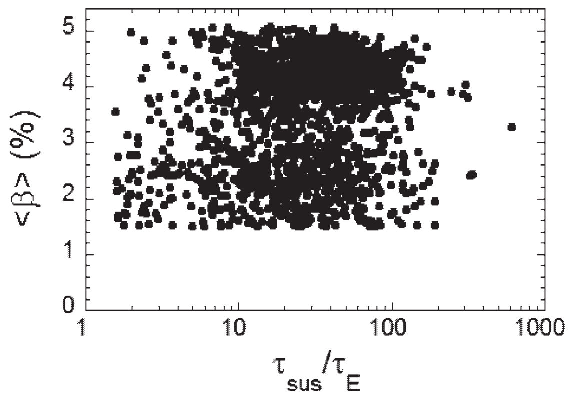

Fig.1: Operational regime on the plane of the volume averaged β, <β> and the sustainment duration normalized by the energy confinement time.

High β regime has been extended not only in β value but also in the duration to sustain high β state (see Fig.1). Quantification of effect of MHD modes on stability and transport has been promoted by accumulated data. Magnetic axis position, R_{ax}, is a key parameter characterizing MHD equilibrium, stability, transport and heating efficiency. A detailed optimization of the magnetic configuration for high-beta plasma production has begun with using a new pulsed power supply for the poloidal coil which can shift R_{ax} by 10 cm in 1.4 s at the magnetic field of 0.5 T. Figure 2 is a typical waveforms of the discharge with this dynamic R_{ax} shift. In this case, β decreases abruptly at 2.23 s due to emergence of strong $m/n = 2/1$ mode. Although the control of R_{ax} has not led to improvement of β yet, the stability boundary has been clarified by this operation.

Since the 10th experimental campaign, enhancement of ion temperature has been pursued by efficient ion heating with a perpendicular neutral beam. In the 12th experimental campaign, the central ion temperature has reached 5.6 keV (see Fig.3). Local transport analysis and fluctuation measurement have indicated that confinement improvement

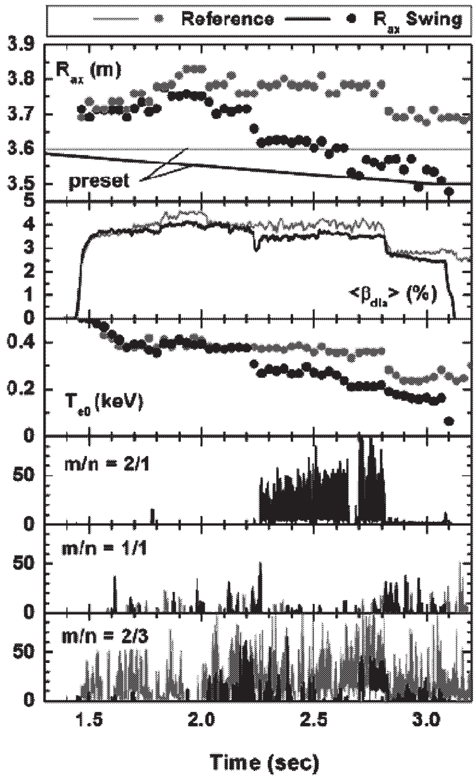

Fig.2: Discharges with (full black) and without (gray) the dynamic magnetic axis shift. From the top, the positions of magnetic axis estimated from the electron temperature profile measured by the Thomson scattering and those of vacuum position, the volume averaged β, the central electron temperature and magnetic fluctuations with major resonances.

like Internal Transport Barrier generates this peaked ion temperature profile. A distinguished feather of this kind of discharge is an accompanied *Impurity Hole* (see Fig.4). HIBP identifies weak negative radial electric field in the core. Despite of this negative electric field, clear outward convection of impurity ions is identified, which cannot be explained the present neoclassical theory.

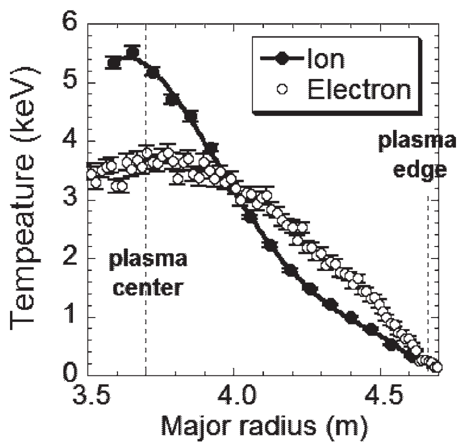

Fig.3: Profiles of ion temperature (solid circles) and electron temperature (open circles).

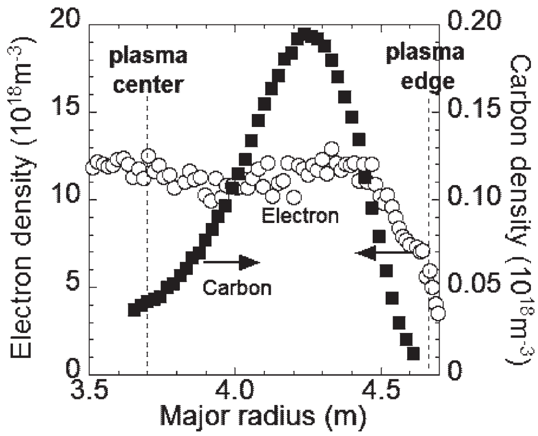

Fig.4: Profiles of electron density (open circles) and carbon density (closed circles).

Assessment of plasma wall interaction has developed in terms of identification of zones undergoing erosion and co-deposition, and reformation of materials in micro-scale. Several divertor plates coated by tungsten via plasma spray has been exposed to LHD plasmas throughout the 12th experimental campaign. Neither significant effect on plasma discharges nor significant damage on the plate has been observed. Impurity screening effect specific to ergodic layer in LHD plays a key role to suppress the influx of impurities

Comparative studies with tokamaks have been promoted in particular by the direct comparisons of the results from LHD with that from JT-60U. Density profile and related particle transport, pedestal structure, response of magnetic islands by ECH, and effect of magnetic shear on transport have been analyzed in order to derive comprehensive understanding of toroidal plasmas. Commonalty and difference due to magnetic configuration is discussed.

Together with the plasma experiment on LHD, design and development of an ion-cyclotron-heating antenna and electron-cyclotron-heating gyrotrons for steady state operation, the second perpendicular neutral beam and the closed helical divertor is moved forward in another experimental campaign. These facilities will upgrade the performance of LHD.

LHD Experiment Technical Guide has been revised to promote domestic as well as international collaboration in LHD experiment, which is now available at http://www.lhd.nifs.ac.jp/en/.

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