(4) Extension of High Temperature Regime and Related Physics

§1. Extension of High-Ion Temperature Regime in 17th Experiment Campaign of LHD

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High ion temperature plasma production is one of the most important missions in LHD project. In 17th experiment campaign of LHD, the new record of the central ion temperature T_{i0} = 8.1 keV was achieved in neutral beam heated plasma with carbon pellet injection (Fig. 1) after wall conditioning main discharges sustained by wave heating$^{1)}$. The record was established by the understanding progress of the effect of wall-conditioning discharge which was found in 15th experiment campaign, and by its effective utilization.

The wall conditioning discharges reduce residual hydrogen gas produced from vacuum wall and other materials inside vacuum vessel. The electron density profile becomes flat or hollow after tens shots of high ion temperature scenario discharges. Thirty to forty shots of wall conditioning discharges change the electron density profile to slightly peaky. The density profile variation increases core ion heating efficiency ($P_i(r_{eff}/a_{99}<0.5)/P_{i,total}$) to 0.55 (#119128) from 0.48 (#119084) due to decrease beam deposition in periphery. The neutral hydrogen particles in bulk plasma decreases ion heating power due to charge exchange loss of injected fast neutral hydrogen particles as beam. The neutral hydrogen particle density profile was measured with newly installed high-resolution H-alpha spectrometer$^{2)}$. The neutral hydrogen particle density was the order of 10^{13} m^{-3} in central region. The decrease of neutral hydrogen density in whole region was observed after the wall conditioning. The charge exchange loss ratio ($P_{CX\text{-}loss}/P_{ion}$) decreased to 0.07 (#119128) from 0.14 (#119084). It was known that ion cyclotron range frequency wave heating (ICRH) is effective for the wall conditioning by 16th campaign. In 17th campaign, it was found that not only ICRH but also electron cyclotron resonance heating (ECRH) are effective for wall conditioning$^{3)}$. These understanding progresses expanded operation variety of wall conditioning discharge and helped more stable and effective wall conditioning discharge operation.

In the high ion temperature plasma scenario, ion thermal transport improves and ion thermal transport barrier (ion-ITB) forms with the foot point at mid minor radius. To design DEMO and future reactors, it is important to evaluate performances as dimensionless parameters. A normalized scale length of ion temperature gradient R/L_{Ti} is one of the dimensionless parameters to evaluate the ion thermal transport performance. The value of R is major radius and L_{Ti} is a scale length of ion temperature gradient $T_i/\nabla T_i$. After ion-ITB formation, the normalized scale length of ion temperature gradient monotonically increase up to about 20 (Fig. 2), which is equivalent and exceeded value to ion-ITB form plasma of large Tokamak devices, such as ASDEX, JET, and DIII-D$^{4)}$.

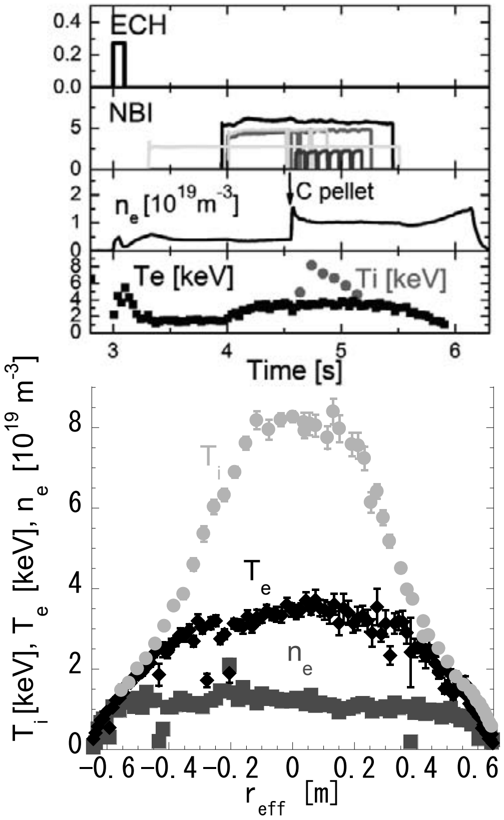

Fig. 1. Discharge waveform (upper) and profile (lower) of central ion temperature record discharge.

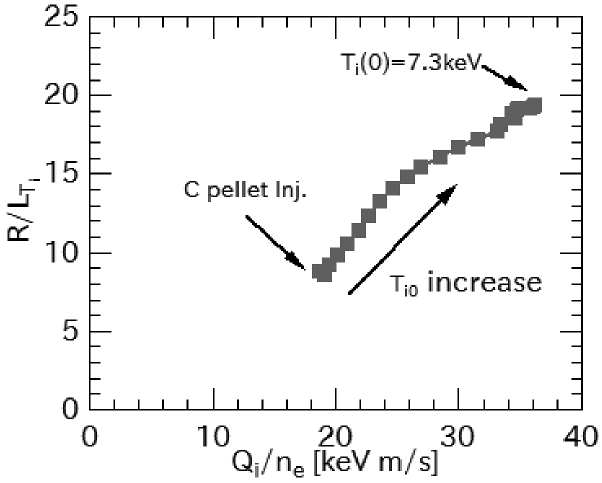

Fig. 2. Relation between normalized ion temperature gradient scale length and heat flux per unit electron density.

1) Nagaoka, K. et al.: FEC2014, Saint Petersburg, Russia, *to be presented.*
2) Fujii, K. et al.: Rev. Sci. Instrum. **85**, 023502 (2014)
3) Takahashi, H. et al.: RFPPC2013, Sorrent, Italy.
4) Nakano, H. et al.: APPC2013, Chiba, Japan.