§4. Achievement of High $T_e$ Plasmas by Upgraded ECRH System in LHD


Since 2006, the installation of 77 GHz gyrotrons with each output power of over 1 MW has progressed in the LHD. These high power gyrotrons enabled us to achieve a higher $T_e$ than that previously obtained and also to survey properties of high $T_e$ plasmas in wide configuration range due to the oscillation frequency selected as 77 GHz, which is different from those of the gyrotrons already installed in the LHD.

Figure 1 shows (a) the radial profiles of $T_e$ for three configuration cases; ($R_{ax}, B_0$) = (3.53 m, 2.705 T) (3.60 m, 2.705 T) and (3.75 m, 2.75 T) with approximately same electron density of $n_e \sim 0.4 \times 10^{19}$ m$^{-3}$. The plasmas were produced and sustained only by centre-focused ECRH with $P_{ECRH} \sim 2.7$ MW. Highly accurate $T_e$ profiles were successfully obtained by the accumulation of the intensity of Thomson scattered light through several fixed discharges with the three YAG lasers all injected together. As can be seen from Fig. 1, the steepest profile and the highest $T_{e0}$ were obtained for $R_{ax} = 3.53$ m. Thus $R_{ax} = 3.53$ m is thought to be better configuration for an achievement of higher $T_e$ plasmas. This result is consistent with a theoretical prediction of neoclassical transport, although the experimentally obtained thermal conductivity was more than ten times larger than the neoclassical one. PHA, SXCCD and ECE measurements showed that non-thermal electrons considerably existed in these high $T_e$, low collisional plasmas. However, we have already confirmed that there was only small amount of influence of the non-thermal electrons on the accuracy of the bulk $T_e$ measurement by Thomson scattering diagnostics. Non-thermal electrons tended to be produced when an ECRH was obliquely injected. The increase of the population of the non-thermal electrons may increase the absorption power to non-thermal electrons and lead to less contribution of ECRH for bulk plasma heating.

Figure 2 shows (a) the radial profiles of $T_e$ for four $n_e$ cases; 0.23, 0.50, 0.73, 0.77 x 10$^{19}$ m$^{-3}$ and (b) the dependence of $T_{e0}$ on density-normalized ECRH power ($P_{ECRH}/n_e$) for $R_{ax} = 3.53$ m, $B_0 = 2.705$ T. The rotational transform ($\pi/2\pi$) profile for a vacuum condition is attached in Fig. 2 (a). Clear threshold of $n_e$ and/or that of $P_{ECRH}/n_e$ for the formation of the e-ITB were found in Fig. 2. The $T_e$ profile drastically changed from a flat one to a peaked one in the narrow range of $0.73 \leq n_e \leq 0.77 \times 10^{19}$ m$^{-3}$. Both the shoulder point of the flat $T_e$ profile and the foot point of the e-ITB coincidently located at the rational surface of $\pi/2\pi = 0.5$. Once the e-ITB formed, $T_{e0}$ increased with the proportional dependence of $-P_{ECRH}/n_e$. Finally more than 15 keV of $T_{e0}$ was successfully achieved for low $n_e$ plasmas ($n_e = 0.2-0.3 \times 10^{19}$ m$^{-3}$).

Fig. 1. Radial profiles of $T_e$ for three configuration cases with $n_e \sim 0.4 \times 10^{19}$ m$^{-3}$. The plasmas were produced and sustained only by centre-focused ECRH.

Fig. 2. (a) the radial profiles of $T_e$ for four $n_e$ cases and (b) the dependence of $T_{e0}$ on density-normalized ECRH power for $R_{ax} = 3.53$ m, $B_0 = 2.705$ T.

5) S. Kubo et al., proceedings of the 16th Joint Workshop on ECE and ECRH, April 12-15, 2010, Sanya, China.