§62. ECRH and ECE in High Electron Temperature, Low Density Plasmas of LHD

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Recent upgrade of the ECRH system in LHD enabled to study the plasma confinement properties at the far low collisional or collision-less regime in the helical system where specific confinement features are predicted from the neo-classical transport theory. These specific features includes confinement degradation in the so called "$1/\nu$" regime where the ripple loss become dominant but radial electric field can drastically alter the situation. ECE is known to be sensitive to the presence of the non-thermal electrons, in other words, ECE spectrum contain information of both the bulk electron and high energy electrons. Appropriate treatment and interpretation of the ECE spectrum can offer the way to clarify the heating and confinement mechanisms of both high energy electrons and bulk electrons.

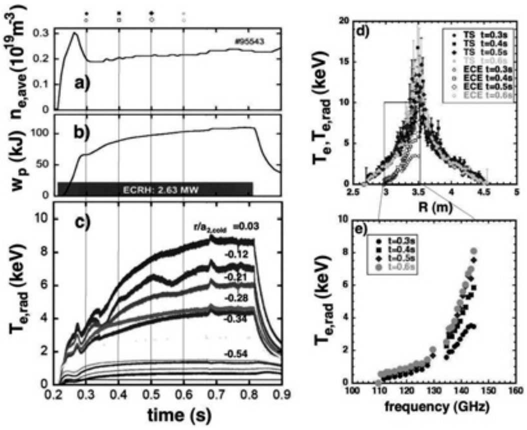

Fig. 1: Time evolutions of the a) $n_{e,ave}$, b) w_p, and c) $T_{rad,ECE}$ during high power (2.63 MW) ECRH injection. d) Electron temperature profile by YAG-Thomson scattering at the time slices t = 0.3, 0.4, 0.5 and 0.6 s. Radiation temperature estimated from ECE are also plotted with open marks as a function of cold second harmonic resonance position. e) Radiation temperature spectrum as a function of frequency at these time slices.

In Fig.1 a)-c) are shown the temporal behaviors of the electron density, dia-mangetic stored energy and ECE radiation temperatures at the frequencies corresponding to the cold second harmonic resonance during a typical low density, high T_e discharge when ECRH(77 GHz) 2.63MW is injected into low density plasma. The bulk electron temperature measured by Thomson scattering indicated 15 keV at the center and has sharp profiles as shown in Fig.1 d). The bulk electron temperature stays almost unchanged in time after t =0.3 s toward the end of ECRH injection. ECE radiation temperature profiles at the same time slices are plotted with open marks as a function of cold second harmonic resonance position. In Fig.1 e) are shown the similar radiation temperature spectrum, but as a function of the center frequency of each channel. It is clear that the radiation temperature is much lower than that expected from the plasma with the same bulk electron temperature, but without high energy electrons.

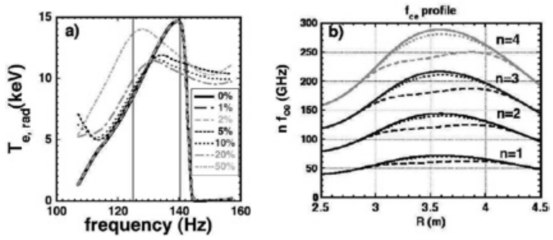

Fig. 2: a) Calculated ECE spectrum assuming $T_{e,bulk} = 15 * (1-\rho^2)^2$ (keV) and $T_{e,high} = 100 * (1-\rho^2)^2$ (keV) and $n_e = 2.0 * (1-\rho^8)^2$ ($\times 10^{18}$ m^{-3}) for various $n_{e,high}/n_e$. b) The dependence o the electron cyclotron and its harmonic frequencies along line of sight. Frequency down shift effect is shown for the electrons of the energy, E_0=15 keV and 100 keV electrons. Here, electron energy is assumed to depend on the minor radius as $E_0(1-\rho^2)^2$.

In order to understand the situation the ECE spectrum with the presence of high energy components are calculated[1]. In this calculation, the radiation transfer equation is integrated along the ECE line of sight backward from the receiving antenna. Calculated radiation temperature spectra are shown in Fig.2 a). When the high energy fraction is less than 2%, the ECE spectrum just reflects the local bulk electron temperature at the second harmonic resonance position, since the only second harmonic resonance layer is optically thick at each frequency. While the high energy fraction increases more than 3%, the situation changes drastically. The radiation temperature at the frequency corresponding to the cold second harmonics near the center even decreases as the high energy fraction increases. It is clear that the cold second harmonic resonance frequency tends to overlap the relativistic downshifted third harmonic frequency. The reason why the radiation temperature near 140 GHz becomes lower than that with high energy fraction below 2 % can be explained by the increase of optical depth at the relativistic down shifted 3rd harmonics in the lower bulk temperature region. Even the fraction of the high energy electrons is small, optical thickness can be affected dramatically, but the local emissivity can stay small, near the bulk electron temperature.

1) S. Kubo *et al.*, J.Plasma Fusion Res. Volume **4**, (2009) S1095.