§6. Electron Bernstein Wave Heating by Long Wavelength Microwave in a Spherical Tokamak and a Helical Device

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On the LATE device at Kyoto University, formation of Spherical Tokamak by ECRH without center solenoid have been conducted [1,2], while on the CHS device at NIFS, experiments for transport study based on the "non-dimensionally similar approach" have been conducted to simulate various transport processes in high temperature plasmas[3]. In both cases, the plasmas are generated and maintained by ECRH in over-dense regime via mode-converted electron Bernstein waves (EBW) from long wavelength microwaves and efficient coupling from external microwaves to EBW is crucial for experiments.

Main objective of the LATE device is to demonstrate formation of ST plasmas by ECH alone without center solenoid. By injecting a 2.45 GHz microwave pulse for 2 seconds with a microwave power up to Prf=35kW, a plasma current has been started and ramped up to 8kA with appropriate control of external vertical field for plasma equilibrium. In the case of a 5 GHz microwave pulse (130 kW, 60 ms), final plasma current reaches 15 kA. In both cases the plasma center locates near the second or third harmonic EC resonance layer as shown in Fig.1 and the line averaged electron density significantly exceeds the plasma cutoff density, suggesting that harmonic EC heating
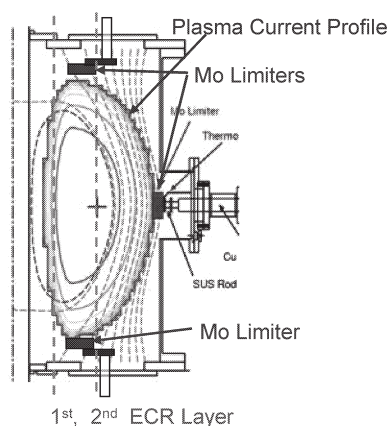

Fig. 1 Heat load to Mo limiters (mainly from high energy fast electrons) roughly amounts to half of the net microwave injection power.

by the mode-converted EBW supports the plasma. Main part of the plasma currents after the closed flux surfaces are formed is seemed to be carried by a fast electron tail as suggested from X-ray measurements where forward emissions are found to be about two times larger than backward emission along the electron drift direction. Direct loss of these fast electrons to the limiters has been estimated by measuring the temperature rise of

molybdenum limiters during discharges as shown in Fig.2. The total amount is about half of the injection power. Absorption rate of EBW by the tail electrons to the bulk electrons estimated by a numerical code is roughly 1/4 to 1/2, depending on the numerical models for fast electron tail, and is roughly consistent with the limiter heat load observation. These results suggest that resultant coupling of injected microwave to EBW is fairly high. It is noted that this does not imply that the single pass mode conversion rate is high since there is a possibility that good coupling is resulted via multi reflections of wave power between the upper hybrid resonance layer and the vessel wall.

In CHS, over-dens plasmas were routinely produced by 2.45 GHz microwaves which were launched perpendicularly or obliquely to the toroidal field[3]. In these experiments, toroidal magnetic field B_t at $R=R_{ax}$ was scanned from 1050 G to 175 G in the magnetic configurations of R_{ax}=97.4cm and 94.9cm, where R_{ax} denotes the magnetic axis position in the vacuum field. In order to measure the absorption profile of injected ECH power, experiments of ECH power modulation were carried out. The modulation frequency was 7kHz or 9kHz. The radial profiles of modulated electron pressure δP_e are shown in Fig.2, for both cases of perpendicular injection of X-mode and oblique injection of O-mode, at B_t=613G. Since the phase differences of δP_e for the modulated ECH power are almost constant over the plasma minor radius, the δP_e profile corresponds to the ECH power deposition profile. The deposition profiles for both injection scenarios of electron cyclotron waves are almost same. For both injection scenarios, ECH power is dominantly absorbed in interior region beyond the O-mode cutoff. This indicates that mode-converted EBW would contribute to production and heating of over-dense plasmas.
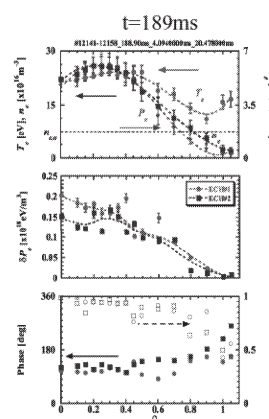

Fig. 2 Radial profiles of T_e, n_e and P_e (top), modulated electron pressure δP_e(middle), and the phase difference and coherence of δP_e (bottom) for modulated ECH power, where B_t=613G and R_{ax}=97.4cm.

References
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