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Non-inductive formation of overdense spherical tokamak plasmas by electron Bernstein waves in the LATE device

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Achievement of non-inductive start-up and formation of spherical tokamak (ST) without the use of central solenoid is one of important issues in order to realize ST-based fusion reactors since ST has a limited space in the center column of the torus. Among the candidates of non-inductive current drive methods, electron cyclotron heating and current drive (ECH/ECCD) is much attractive from the view point of reactor design since the microwave power for ECH/ECCD can be injected through a small launcher located far away from the plasma surface. Moreover, when the injected microwave is converted to electron Bernstein wave (EBW), it can propagate in the overdense plasma and make ECH/ECCD without density limit.

In the Low Aspect ratio Torus Experiment (LATE) device which has no center solenoids, experiments on non-inductive start-up and formation of ST by ECW/EBW heating & CD have been carried out. The vacuum vessel is a cylinder with an inner diameter of 1 m and a height of 1 m and the diameter of center column is 0.114 m. The microwaves at 2.45 GHz and 5 GHz are injected from the low-field side of the torus on the midplane in O-mode obliquely to the toroidal field with an angle of ~75 degree. The typical discharge duration is 0.1 ~ 0.2 sec.

A torus plasma is initiated by breakdown at the fundamental electron cyclotron resonance (ECR). When a weak vertical field (~15 G) is applied, a pressure-driven current flows in the initial open field configuration [1,2]. Then, the energetic electron component develops under the modified magnetic field by the self-current. The initial closed flux surfaces are produced when an additional current is driven by so-called cross-field passing electrons (CFPE) [3,4].

After the formation of closed flux surfaces, ECCD mechanism by Fisch and Boozer [5] becomes effective and principal because both pressure-driven and CFPE-driven currents cannot flow in the closed flux surfaces. The density in the core region exceeds the plasma cutoff density and injected microwaves in O-mode should be reflected back at the cutoff layer. Some amount of power is reflected in X-mode and mode-converted to EBW at the upper-hybrid resonance (UHR) layer (O-X-B mode conversion scheme), and propagates to the ECR layer where the wave power is absorbed [6,7]. EBW can have high refractive index along the magnetic field, N//, and heat the high energy electrons in the low field side of ECR due to the large Doppler shift in the resonance condition. The high N// EBW produces collisionless high energy electrons with large parallel momentum and ramp the plasma current with a rate comparable to that by lower-hybrid waves [8]. When EBW is excited in the 1st propagation band and the fundamental ECR layer is located at the center of the plasma, highly overdense plasmas with ~7 times the plasma cutoff density are produced [9,10]. For effective EBW heating & CD, polarization adjustment for O-X-B mode conversion scheme is necessary [6]. Improvement of CD is demonstrated by increasing the amount of X-mode like polarization power when the density becomes high and the density scale length at UHR becomes short [11], which is qualitatively in accordance with the mode conversion rate calculated with the cold resonance absorption model in the slab geometry.

Recently, experiments on non-inductive formation of ST with two frequencies have been carried out. There are the fundamental ECR layer for 2.45 GHz and the fundamental, second and 3rd ECR layers for 5 GHz in the plasma. It is shown that when the 2nd EBW at 5 GHz is superposed to the plasma produced non-inductively by the 1st EBW at 2.45 GHz, high energy tail electrons are heated strongly and the plasma current is rapidly increased, while the bulk plasma parameters are nearly the same. This selective tail electron heating is qualitatively explained by the absorption characteristics of EBW that in the case of low ratio of density to the cutoff density the electric field of EBW is strong and the absorption by the high energy tail electrons becomes large in the low field side at Doppler shifted ECR before EBW reaches the absorption region of the bulk electrons.

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