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Formation of spherical tokamak at 10 times the plasma cutoff density on LATE
LATEでの遮断密度の10倍を超える電子密度領域での球状トカマク形成

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This paper reports on start-up and formation of a spherical tokamak (ST) plasma with ~ 10 times the plasma cutoff density solely maintained by electron Bernstein (EB) waves. The plasma current reaches up to Ip = 10 kA under a 2.45 GHz microwave power of 60 kW, 250 ms pulse. The dependence on the electron cyclotron resonance (ECR) location for start-up discharges has been investigated. It is found that the bulk electron density significantly increases when the ECR layer locates slightly inboard side of the vacuum vessel center. In this configuration, better coupling to the EB waves at the first propagation band (between the fundamental and 2nd ECR) and effective heating of bulk electrons at the plasma core are indicated.

1. Introduction

Tokamaks need the toroidal plasma current, which is usually initiated and maintained by induction from a center solenoid (CS). If CS can be eliminated from the device, the structure of tokamak reactors will be greatly simplified, which may enable economical fusion reactors [1]. For this purpose, start-up and formation of ST by electron cyclotron heating and current drive (ECH/ECCD) have been studied in the Low Aspect ratio Torus Experiment (LATE) device. ECH/ECCD method is eminently favorable for reactors since the wave beam can be injected via a small launcher remote from the plasma.

This paper reports a startup and formation of an ST plasma with ~ 10 times the plasma cutoff density solely maintained by electron Bernstein (EB) waves, where the plasma current is ramped up to Ip = 10 kA by 2.45 GHz microwave power of 60 kW, 250 ms pulse.

2. Experimental Setup

The experiments are performed in the LATE device, whose vacuum vessel is a cylinder with an inner diameter of 1m and a height of 1m. The center post with an outer diameter of 11.4cm encloses 60 turns of conductors for the toroidal field. There is no CS for the inductive current drive.

Three 20 kW and one 5 kW magnetrons at 2.45 GHz are used for EC heating. Each power is launched obliquely to the toroidal field from the low field side on the midplane, via a cylindrical launcher of open waveguide type. The polarization is linearly polarized one where the electric field lies on the midplane, and is mainly in the O-mode.

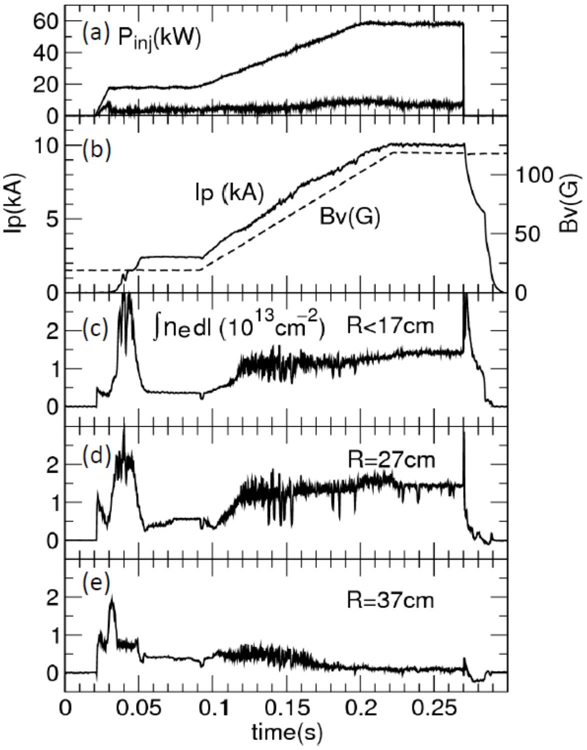

Fig.1. Typical discharge

3. Experimental Results

Figure 1 shows a typical discharge. A steady toroidal field of Bt = 720 G and a vertical field of Bv = 20 G (both at R = 25 cm) are applied before the microwave injection. A plasma current is initiated and closed flux surfaces are formed via a current jump under a steady vertical field [2]. After the closed flux surfaces are formed, the plasma current ramps up with an increase of the microwave power and the equilibrium Bv and reaches Ip = 10 kA at Bv = 120 G (Figs. 1(a) and (b)). The three chords interferometer measurement shows that the electron density inside the last closed flux surface significantly increases as Ip increases (Figs. 1(c)-(e)). At the final stage, the line-averaged density along R = 27 cm reaches ~ 10 times the plasma cutoff density, suggesting that the plasma is maintained solely by EB waves.

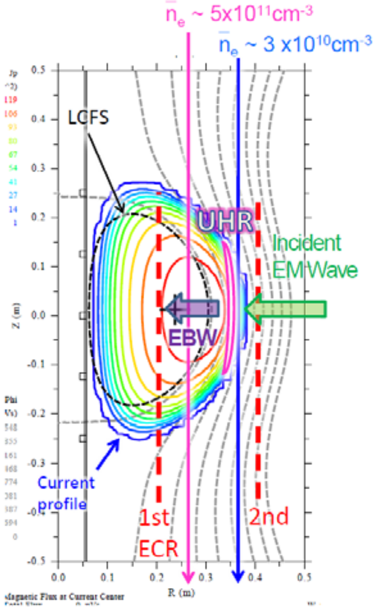

Fig.2 Poloidal flux contours and current profile

Figure 2 shows the poloidal flux contours and the current profile estimated from the magnetic analysis at Ip = 10 kA (t = 0.25 s). In this discharge, the upper hybrid resonance (UHR) layer location is estimated to be between the fundamental EC resonance layer (R = 20.6 cm) and the second harmonic one. Incident electromagnetic waves are expected to be mode-converted to EB waves in this first propagation band and then effectively heat the bulk electrons at fundamental ECR located near the plasma core. Soft X-ray and extreme ultraviolet emission profiles show significant increases just outside of the ECR layer as Ip increases. In addition, impurity line radiations at higher excitation energies such as CV (304 eV) and OV (72 eV) strongly increase compared with the density increment. These suggest that the bulk electron temperature also increases by EB heating.

On the other hand, when we set the ECR layer at R = 19.2 cm, the electron density significantly decreased, while the plasma current is ramped up to the same value of Ip ~ 10 kA under the same injection power. In this case, the current profile expands to the outside of the 2nd harmonic ECR layer and the UHR layer is estimated to be close to or outside the 2nd harmonic ECR layer. Magnetic analysis [3] shows a large perpendicular pressure region exists near the 2nd harmonic ECR layer. These suggest that a larger portion of the injected power is coupled to the high energy trapped electrons by the 2nd harmonic heating of EB waves in this configuration.

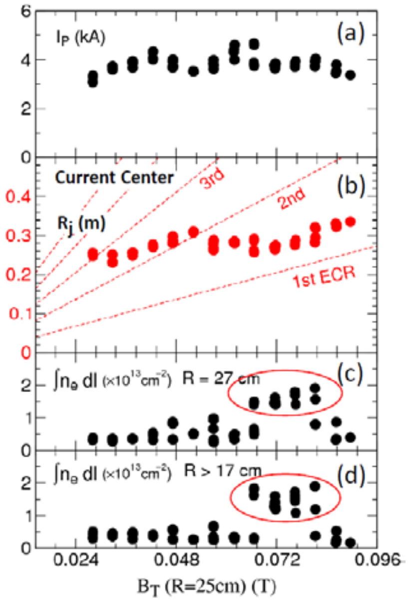

Fig. 3 Dependence on ECR location

Figure 3 shows the dependence on the ECR location for similar discharges where plasma currents are ramped up to Ip ~ 4kA. It is clearly shown that the electron density significantly increases when the fundamental ECR is located at R = 20-22 cm (Bt ~ 0.07 – 0.08 T), slightly inboard side of the vessel center, and the 2nd harmonic layer is located at close to the vessel wall of R = 50 cm (Figs.3 (b)-(d)). In this configuration, the UHR layer is located between the fundamental and 2nd harmonic ECR layer, resulting in a better coupling to EB waves at the first propagation band and the effective heating of bulk electrons at the fundamental ECR.

References

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