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Formation of microwave spherical torus by electron Bernstein wave heating and current drive on LATE
LATEにおける電子バーンスタイン波加熱・電流駆動によるマイクロ波球状トーラスの形成

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In the Low Aspect ratio Torus Expreiment (LATE) device non-inductive formation of spherical torus (ST) by electron Bernstein (EB) wave heating and current drive has been explored. A highly overdense ST plasma where the plasma current reaches up to 12 kA and the line averaged electron density exceeds more than 7 times the plasma cutoff density has been formed and maintained steady for 50 ms with a 2.45 GHz microwave power of 60 kW. To extend the density and the plasma current, polarizers have been installed in three transmission lines of the 2.45GHz injection system to adjust the injection polarization to improve the coupling to the EB waves. The experimental results with 80 kW injection power using fully polarized waves will be presented.

1. Introduction

There has been a considerable interest in non-inductive start-up of Tokamak plasma without the use of the central solenoid (CS). If the plasma current can be non-inductively started up, the CS could be reduced or eliminated from the Tokamak device. Then the structure of the Tokamak fusion reactor will be highly simplified [1]. For the spherical torus (ST) based fusion devices [2] elimination of the CS is crucial since there is only a severely restricted space in the center column of ST to hold an aspect ratio sufficiently low.

In the Low Aspect ratio Torus Experiment (LATE) device non-inductive formation of ST by electron Bernstein (EB) waves has been explored. The previous experiments show that EB wave heating and current drive is quite effective for the current initiation, the formation of closed flux surfaces and a rapid current ramp-up [3-5]. In this paper we report a startup and formation of highly overdense ST plasma where the plasma current reaches up to 12 kA and the line averaged electron density exceeds more than 7 times the plasma cutoff density. The effect of the injection polarization on the mode conversion rate to EB waves at the extremely overdense regime is also reported.

2. Experimental Setup

The experiments are performed in the LATE device. The 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.

Four 20 kW, 0.2 sec magnetrons at 2.45 GHz are used for electron cyclotron (EC) heating and current drive. Each power is launched obliquely to the toroidal field from the low field side on the midplane via a circular open waveguide launcher as shown in Fig. 1. Three polarizers have been installed in the three transmission lines on the port 2R, 8R and 10R to adjust the injection polarization for the better coupling to the EB waves at the extremely overdense regime. The polarization on the port 4R is linearly polarized one where the

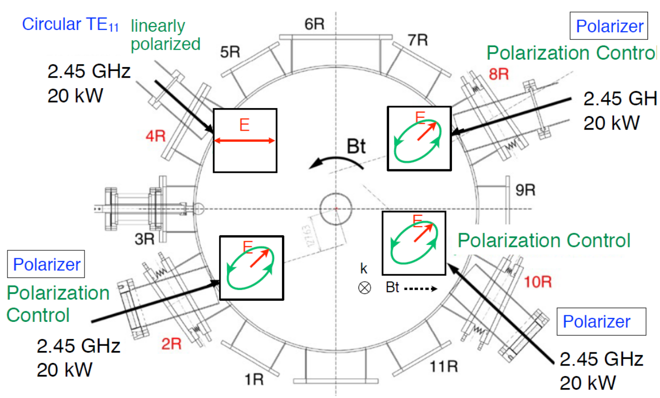

Fig.1. 2.45 GHz launcher system

electric field lies on the midplane.

3. Experimental Results

Figure 1 shows a typical discharge. A steady toroidal field of B_T = 720 G and a vertical field of Bv = 15 G (both at R = 25 cm) are applied before the microwave injection. When the microwaves are injected a plasma current is easily initiated and closed flux surfaces are formed via a current jump under a steady vertical field. After that the plasma current is ramped up with ramps of the microwave power and the vertical field for equilibrium.

Among many attempts with combinations of the polarization and microwave power control, the largest plasma current and highest density have been obtained by injecting ~40 kW microwave power with a X-mode like polarization and ~20 kW power with an O-mode like polarization as shown in Fig. 1(a). Note that at the early stage of discharges where the density is low and the density gradient also low, the O-mode like polarization has a high mode-conversion efficiency to EB waves, while the X-mode like polarization is favorable at the last stage of discharges where the plasma is highly overdense and the density gradient becomes high. The plasma current ramps up to 12 kA and the line-averaged density on the midplane reaches 5.5×10^{17} m^{-3} (L = 0.55 m inside the last closed flux surface (LCFS)), which is more than 7 times the plasma cutoff density. Comparing with the result where all the power is injected with the O-mode like polarization, the density is almost the same and the plasma current 20 % higher. Further experiments with 80 kW injection power using fully polarized waves are ongoing and the results will be presented.

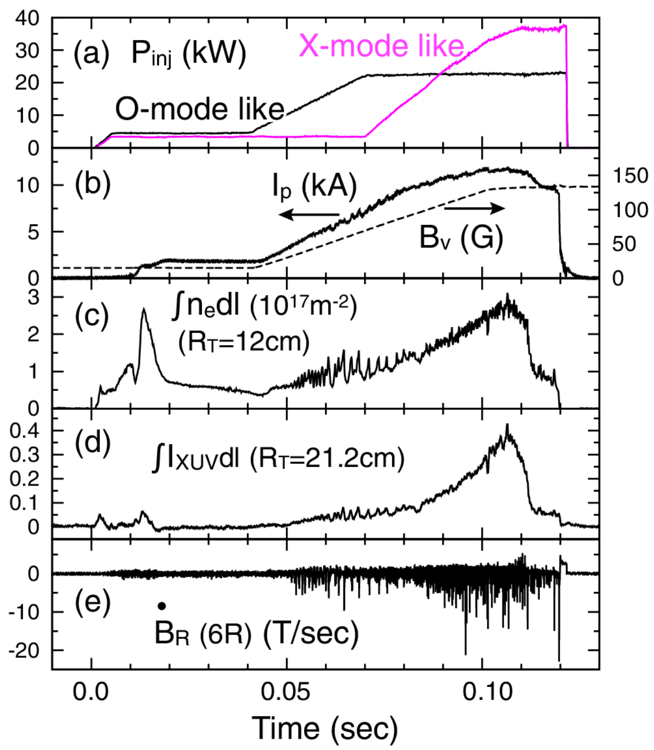

Fig.2. Typical discharge. (a) injection microwave power of O-mode like polarization and X-mode like one, (b) plasma current and vertical field strength at R = 25 cm (c) line-integrated density along the horizontal chord at a tangency radius of R_T = 12 cm, (d) line-integrated extreme ultraviolet emission signal on midplane at a tangency radius of R_T = 21.2cm, (e) dB_R/dt signal on magnetic probe on the port 6R.

In the discharge shown in Fig. 2 the increment in Ip becomes slower when Ip > 10 kA. In this stage, intermittent plasma ejections across the LCFS are observed. These events are characterized by large spike signals on magnetic probes as shown in Fig. 2(e). The difference of two consecutive visible camera images upon the event clearly indicates that the intensity decreases inside the LCFS and increases outside the LCFS, showing the plasma is ejected across the LCFS. The line-integrated density in the horizontal chord decreases ~40 % on the largest drop and slowly recovers until the next event. Repetition of such large ejection events causes a gradual decrease in the density and the plasma current. Suppression or mitigation of these events is therefore required to reach the higher density and higher current. Further observations on these events with additional magnetic probes and study on the dependence on poloidal field geometries will be also presented.

References

[1] S. Nishio, et al.: *Proc. 20th Int. Conf. on Fusion Energy* (Vilamoura, 2004) FT/P7-35.
[2] Y.-K. M. Peng et al, *Proc. 23rd Int. Conf. on Fusion Energy* (Daejeon, Korea, 2010)
[3] M. Uchida et al, *Proc. 24th Int. Conf. on Fusion Energy* (San Diego, USA, 2012)
[4] T. Yoshinaga, et al.:Phys. Rev. Lett.**96**(2006) 125005
[5] M. Uchida, et al.:Phys. Rev. Lett. **104** (2010) 065001