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Dynamics of internal transport barrier formation in LHD

LHDにおける内部輸送障壁形成のダイナミクス

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The dynamics of internal transport barrier (ITB) formation is studied by means of the modulation electron cyclotron resonant heating (MECH) experiment in large helical device (LHD). The ITB is formed when the MECH is in the on-phase. Repetitive sequence of the ITB formation/deformation is obtained with the MECH frequency. By using the conditional average technique, time evolution of the electron temperature and its gradient are observed in detail, during the ITB formation. High frequency turbulence amplitude is also measured with the microwave reflectometry. Temporal response in the turbulence amplitude is discussed.

1. Introduction

Understanding of improved confinement modes, such as Edge Transport Barrier (ETB) in H-mode discharge and Internal Transport Barrier (ITB), is regarded as a key factor to realize thermonuclear fusion reactor [1]. In particular, turbulence transport suppression mechanisms in the ETB plasmas have been intensely discussed, focusing on the important role of the edge sheared radial electric field structure as the regulator of turbulence transport [2]. However, for the ITB plasmas, understanding of the critical role of electric field for the turbulence transport suppression is still challenging.

In the Large Helical Device (LHD), the ITB is observed associated with the electron root discharge where the neoclassical transport is reduced due to strong radial electric field [3]. In the last experimental campaign, heating power modulation experiment in the ITB plasma is successfully performed, aiming to investigate the dynamics of ITB formation. By observing temporal response of the fluctuation in the high frequency turbulence regime, one can assess the effect of the ITB formation on the turbulence transport.

2. Experimental setup

The experiments were performed with two units of electron cyclotron resonant heating (ECH). One ECH was used to sustain the plasma, meanwhile the other was for heating modulation. Sequential heating modulation was performed with the frequency of 15 Hz. Figure 1 shows typical time evolution of the plasma parameters in the discharge we analyzed (#119028). The time interval t = 1.3-1.9 s is analyzed here. During the time interval, the line averaged electron density is almost constant in time. Other experimental parameters were follows: the magnetic axis of R_{ax} = 3.6 m, toroidal magnetic field strength of B = 2.75 T, and line averaged electron density of $\langle n_e \rangle \sim 1\times10^{19}$ m^{-3}.

Time evolution of the electron temperature was measured with a multi-channel ECE radiometer system. In addition, turbulence behavior in the electron density fluctuation was observed with a microwave reflectometry. During modulation ECH phase, electron density profile was found to be almost constant, which allows us to access the fixed radial location with the reflectometry system. In order to analyze the heat pulse propagation, we use the conditional averaging method [4].

3. Experimental results

Figure 1 (d) shows time evolution of the electron temperature measured with Thomson scattering system with the acquisition frequency of 15 Hz, which is synchronized with the MECH period. Core (3.4 m < R < 3.8 m) temperature modulation is clearly seen whereas the temperature in the other location (R < 3.4 m, R > 3.8 m) does not show a strong response to the MECH.

Figure 2 shows the electron temperature profiles when the modulation ECH is in the off-phase (black closed square) and on-phase (red open square). The boundary of the transport barrier, which is called ITB foot-point, is located at R ~ 3.8 m in the low field side (major radius larger than the magnetic axis, $R > R_{ax}$ = 3.6 m). From the time evolution of the electron temperature and its gradient, dynamics of the ITB formation is discussed.

Turbulence behavior in the electron density fluctuation is observed with the microwave reflectometry. Low frequency coherent oscillation at the frequency of $f \sim$ 1-2 kHz is observed, which is also seen in the electron temperature fluctuation and magnetics fluctuation measured with the ECE radiometer and the Mirnov coils, respectively. In addition, high frequency turbulence spectrum is observed at the range of $f <$ 100-200 kHz. Fluctuation amplitude of both the low frequency mode and the high frequency turbulence are modulated with the MECH frequency. Temporal response of each fluctuation component is discussed in detail, as has been performed in Ref. [5].

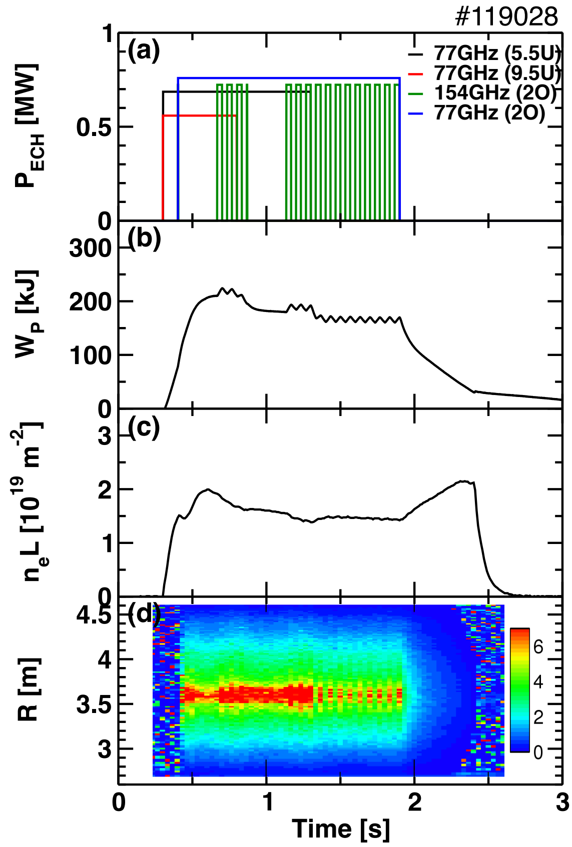

Figure 1: Time evolutions of (a) ECH power (b) plasma confined energy (c) line integrated density and (d) electron temperature observed with Thomson scattering.

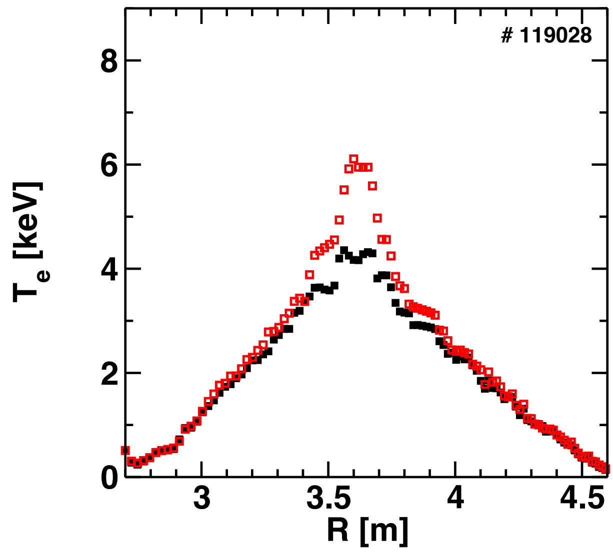

Figure 2: Radial profiles of electron temperature when the modulation ECH is in the off-phase (black closed square) and on-phase (red open square), respectively.

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