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Nonlinear Process of Electron Temperature Gradient Driven Turbulence
電子温度勾配乱流の非線形過程

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The Electron temperature gradient (ETG) mode is found to be excited by the ETG formed using a novel method involving the superimposition of high- and low-temperature electrons in the linear magnetized plasmas. The ETG mode is saturated when its fluctuation amplitude exceeds the threshold, while the low-frequency fluctuation associated with a collisionless drift wave (DW) mode is enhanced concurrently with an abrupt increase in the bicoherence between the ETG mode and the DW mode. Therefore, the multi-scale nonlinear coupling causes the energy transfer from the ETG mode to the DW mode when the ETG mode exceeds a certain threshold. In addition, the effects of the radial electric field (E_r) on the suppression of ETG mode are investigated. The sufficiently large E_r can suppress the ETG mode regardless of its signs. Even when E_r becomes small, on the other hand, the ETG mode amplitude is decreased in the slightly negative E_r by the energy transfer of ETG mode to DW mode through the multi-scale non-linear coupling, which consequently causes the new suppression mechanism of the ETG mode.

1. Introduction

Understanding and controlling the anomalous heat transport are critical challenges for improvement of the plasma confinement. Recently, the electron temperature gradient (ETG) mode has been proposed as the strongest candidate responsible for anomalous heat transport [1-4], which is difficult to be clearly explained, even though numerous researchers have investigated the mechanisms of ETG mode induced anomalous transport. In contrast, low-frequency fluctuations such as the drift wave (DW) mode are well reported to cause the transport. According to our recent results by precisely controlling the ETG [5,6], the ETG mode (~0.4 MHz) is supposed to affect the growth and suppression of the DW mode (~7 kHz). Therefore, we investigate the multiscale nonlinear interaction of the ETG mode and the DW mode using the bispectral analysis [7] in the linear magnetized plasmas.

2. Experimental Apparatus

Experiments were performed in the Q_T-Upgrade machine at Tohoku University. The ETG was formed by superimposing low-temperature thermionic electrons (~0.2 eV) emitted from a tungsten hot plate and high-temperature electrons (~4 eV) in an electron cyclotron resonance (ECR) plasma (microwave power $P_\mu = 20$ W), which then passed through two different-shaped stainless-steel (SUS) mesh grids. Hereinafter, the voltages applied to the mesh grids are defined as V_{g1} (grid 1) and V_{g2} (hollow grid 2). The hot plate used as the electron emitter was concentrically segmented into three sections, where the outermost electrode was kept grounded, and the central (V_{ee1}) and peripheral (V_{ee2}) electrodes were biased in the range of $V_{ee1,ee2} = -10 \sim +10$ V. The ∇T_e is obtained as the local ETG in the region of $r = 0.5 \sim 2.0$ cm.

3. Experimental Results and Discussion

Figure 1 gives (a) the normalized amplitudes $\tilde{I}_{es}/\bar{I}_{es}$ of fluctuations with ETG and DW modes and (b) bicoherence between the ETG and the DW modes as a function of the electron temperature gradient ∇T_e between the central and peripheral regions of the plasma. The $\tilde{I}_{es}/\bar{I}_{es}$ of ETG mode gradually increases with an increase in ∇T_e, however $\tilde{I}_{es}/\bar{I}_{es}$ is saturated when ∇T_e is higher

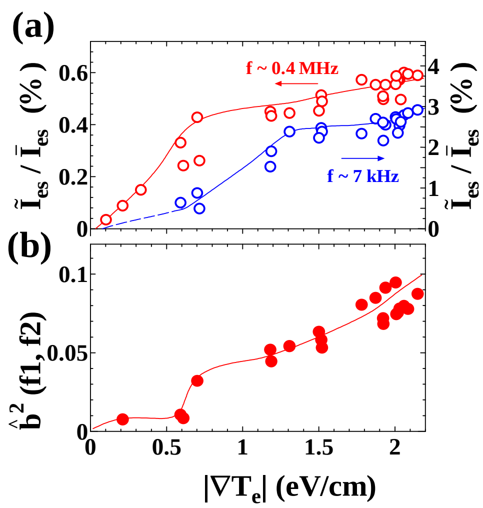

Fig. 1. (a) $\tilde{I}_{es}/\bar{I}_{es}$ of fluctuations with ETG and DW modes and (b) bicoherence between the ETG and the DW modes as a function of ∇T_e.

than ~0.7 eV/cm. On the other hand, the $\tilde{I}_{es}/\bar{I}_{es}$ of the DW mode starts to increase when the magnitude of ∇T_e is larger than 0.7 eV/cm. Furthermore, the bicoherence between the ETG mode and the DW mode drastically increases for $\nabla T_e \geq 0.7$ eV/cm. Therefore, it is considered that the nonlinear coupling is strongly enhanced when ∇T_e exceeds 0.7 eV/cm, and consequently the energy of the ETG mode is transferred to the DW mode through the nonlinear interaction.

To investigate the effects of radial electric fields on the suppression of the ETG and DW modes, the bias voltages to the electron emitter is controlled. Figure 2 presents the normalized amplitudes $\tilde{I}_{es}/\bar{I}_{es}$ of fluctuations with high and low frequencies for (a) $\nabla T_e \simeq 1.0$ eV/cm and (b) $\nabla T_e \simeq 2.4$ eV/cm as a function of E_r for $V_{g1} = -10$ V and $V_{ee2} = -1.5$ V at $r = -0.9$ cm. In the case of $\nabla T_e \simeq 1.0$ eV/cm, the ETG mode is symmetrically suppressed by the $E{\times}B$ drift velocity shear effects owing to the large E_r, which is consistent with the theoretical estimation by Gao *et al.* [8]. In addition, the DW mode decreases with an increase in the E_r regardless of its sign, which is also consistent with the numerical calculations on the effect of E_r on the DW mode.

On the other hand, in the case of strong ETG, i.e., $\nabla T_e \simeq 2.4$ eV/cm, the stabilized characteristics of the ETG mode and the DW mode on the effect of E_r are significantly different from those in the case of $\nabla T_e \simeq 1.0$ eV/cm [Fig. 2(b)]. It is observed that the $\tilde{I}_{es}/\bar{I}_{es}$ of the ETG mode is increased in the slightly positive E_r, while it is decreased in the negative E_r. In contrast, the $\tilde{I}_{es}/\bar{I}_{es}$ of the DW mode is decreased in the slightly positive E_r, while it is

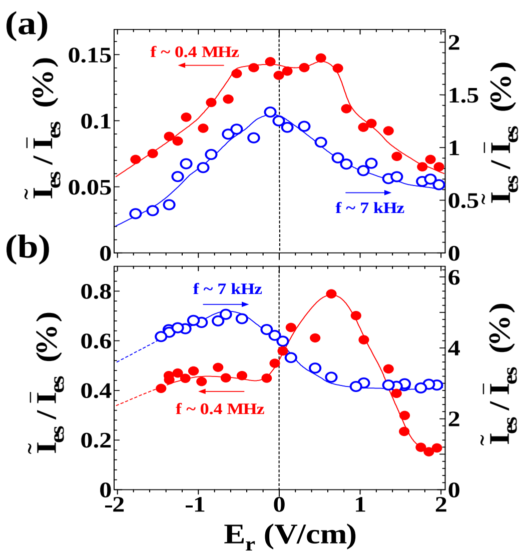

Fig. 2. The normalized amplitudes $\tilde{I}_{es}/\bar{I}_{es}$ of fluctuations with high and low frequencies of (a) $\nabla T_e \simeq 1.0$ eV/cm and (b) $\nabla T_e \simeq 2.4$ eV/cm as a function of the E_r.

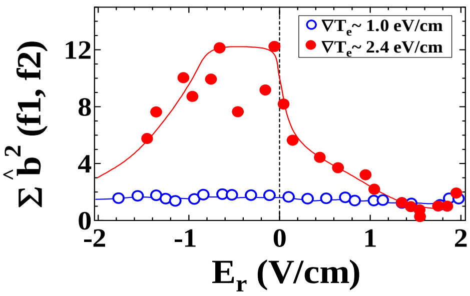

Fig. 3. The integrated bicoherence between ETG and drift wave modes as a function of the E_r.

increased in the negative E_r. It is to be noted that the dependence of the ETG mode on E_r is definitely different from the case of the DW mode, which is considered to be caused by the nonlinear interaction between the ETG mode and the DW mode.

Figure 3 shows the E_r dependence of the integrated bicoherence in the range of $f_1 \simeq 0.4 \sim 0.8$ MHz, where f_2 is 6 ~ 8 kHz (DW mode) in order to quantitatively investigate the nonlinear coupling with respect to the ETG mode. In the case of $\nabla T_e \simeq 2.4$ eV/cm, the bicoherence suddenly increases when the E_r becomes negative value. Therefore, it is concluded that when the E_r becomes slightly negative, the nonlinear coupling between the ETG and DW modes is increased, and then, this nonlinear coupling enhances the energy transfer from the ETG mode to the DW mode, causing the effective suppression of the former even in the small negative E_r.

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