Low and high frequency fluctuations excited by electron temperature gradient in magnetized plasmas

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Electron temperature gradient (ETG) perpendicular to magnetic field lines is formed by superimposing high-temperature electrons of an electron cyclotron resonance (ECR) plasma upon low-temperature thermionic electrons emitted from a tungsten hot plate, which pass through two different-shaped mesh grids. The formed ETG is found to excite a high-frequency fluctuation, i.e., ETG mode, and furthermore, to enhance a low-frequency fluctuation originally caused by the E×B shear through the coupling between the high and low frequency fluctuations.

I. Introduction

In recent years, anomalous electron heat transports in magnetically confined plasmas are a big issue [1], which are difficult to be explained clearly even though many researchers try to understand the mechanism of the heat transports in fusion devices [2]. There are strong experimental evidences that the anomalous heat transports are attributed to an electron temperature gradient (ETG) driven instability (ETG mode). Actually, it is seen that the instability is driven by the ETG and nonlinear effects of the ETG mode generate the significant electron transport. In addition, it is theoretically reported that the ETG mode is difficult to be suppressed by E×B velocity shears, which is different from the ion temperature gradient mode [3]. Although there are some earlier theoretical [4], numerical [5], and experimental [6] studies on the ETG mode, experimental observations of the ETG mode in large fusion devices are not sufficient to clearly explain the excitation mechanism, which is caused by the restricted experimental condition in the magnetically confined fusion plasmas.

In the laboratory experiments, on the other hand, several advanced techniques have been applied to the control of the electron temperature [7]. Thus the aim of this work is to control the ETG by using a novel method superimposing high and low temperature electrons in a basic plasma device in order to understand the excitation mechanism of the ETG mode.

II. Experimental Apparatus and Method

Experiments are carried out in a linear machine (Q_T-Upgrade) of Tohoku University, the schematic of which is shown in Fig. 1. In order to form the ETG, we divide the machine into two sections. One is called as a source region where an electron cyclotron resonance (ECR) plasma with high electron temperature is generated and the other is called as an experimental region where the high-temperature electrons of the ECR plasma are superimposed on low-temperature thermionic electrons. Here, the axial center of the machine is defined as $z = 0$ cm. In the source region, a magnetic field is well shaped and the bottom of the well is set to be the electron cyclotron resonance field $B_{ECR} = 0.214$ T. The Ar gas and a microwave are used to control the electron density and temperature in the experimental region. Two types of stainless mesh grids [grid 1 (ϕ6 cm, 10 mesh/inch) and grid 2 (doughnut shape, outside diameter: ϕ6 cm, inside diameter: ϕ3 cm, 30 mesh/inch)] are located at $z \approx -40$ cm and divide the source region from the experimental region. The ETG is easily formed by controlling the applied bias voltage of the grids. A tungsten (W) hot plate set at the end of the experimental region is heated by applying DC power $P_{HP} = 3$ kW and generates the low-temperature thermionic electrons ($T_e = 0.2$ eV), which works as an electron emitter. Since the electron emitter is concentrically segmented into two sections, a radial profile of the space potential is controllable by applying different bias voltages between central (V_{ee1}) and peripheral (V_{ee2}) sections of the electron emitter. The low-temperature thermionic electrons compensate the density gradient of the ECR plasma penetrating the grid 2. Therefore, the large ETG is formed in the experimental region keeping the radial density profile uniform. A Langmuir probe is used to measure radial profiles of plasma parameters at $z = 0$ cm in the experimental region [7].

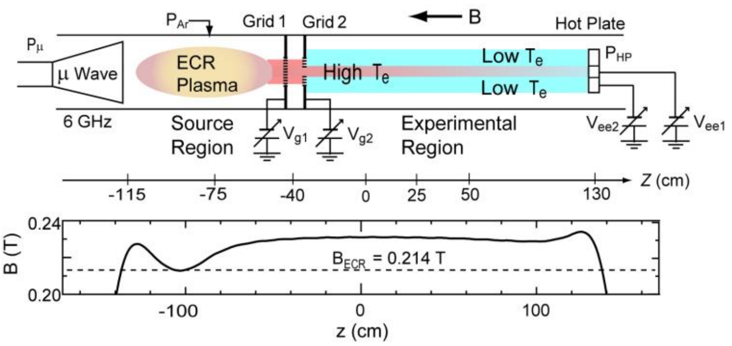

Fig. 1. Schematic diagram of the experimental apparatus and an axial profile of the magnetic field strength.

III. Experimental Results and Discussion

Using this novel method superimposing the high-temperature electrons on the low-temperature electrons with spatially control, the ETG can be formed in the experimental region.

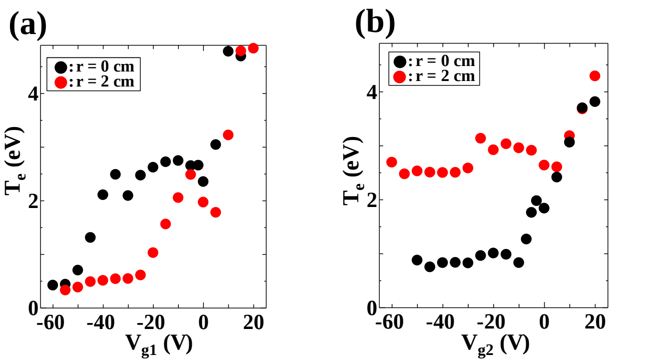

Fig. 2. Electron temperature (T_e) in the central and peripheral regions as functions of (a) V_{g1} for floated V_{g2}, and (b) V_{g2} for floated V_{g1} at $P_\mu = 30$ W.

Figure 2 shows the electron temperature as functions of the bias voltages of (a) grid 1 (V_{g1}) and (b) grid 2 (V_{g2}) in the radially central ($r = 0$ cm) and peripheral ($r = 2$ cm) regions for $P_\mu = 30$ W. When the applied bias voltage of grid 2 is decreased, the electron temperature only in the peripheral region is rapidly decreased, while the electron temperature in the central region is almost constant. Therefore, the electron temperature difference between the central and peripheral regions, i.e., the ETG, is easily formed by controlling V_{g2} with an appropriate adjustment to V_{g1}.

Figures 3 and 4 show radial profiles of the electron temperature (T_e) and plasma potential (ϕ_s), respectively, for (a) $V_{ee1} = V_{ee2} = 0$ V and (b) $V_{ee1} = 0$ V, $V_{ee2} = -3$ V. In Fig. 3, the ETG is found to be formed by controlling the applied bias voltage V_{g2}. Furthermore, it is revealed that the formation of the ETG is independent of the bias voltage V_{ee2}. On the other hand, the radial profiles of the space potential can be controlled by V_{ee2} as shown in Fig. 4, which can generate the E×B shear.

Figure 5 shows the normalized amplitudes $\tilde{I}_{es} / \bar{I}_{es}$ of fluctuations with low and high frequencies as a function of V_{g2} ($\bar{I}_{es}$: time averaged value of I_{es}) for (a) $V_{ee1} = V_{ee2} = 0$ V, V_{g1}

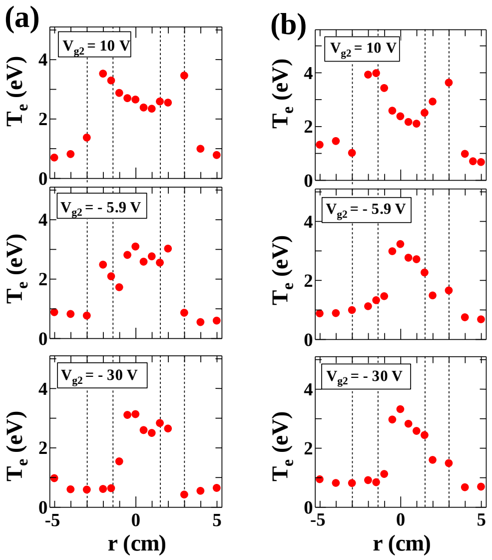

Fig. 3. Radial profiles of electron temperature with V_{g2} as a parameter for (a) $V_{ee2} = 0$ V and (b) $V_{ee2} = -3$ V. $V_{ee1} = 0$ V, $V_{g1} = -10$ V, and $P_\mu = 30$ W.

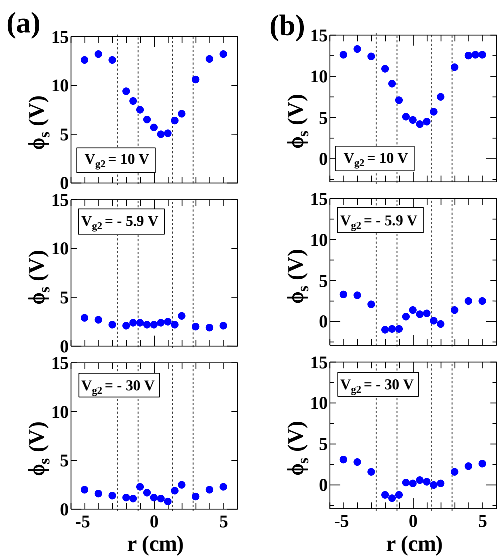

Fig. 4. Radial profiles of space potential with V_{g2} as a parameter for (a) $V_{ee2} = 0$ V and (b) $V_{ee2} = -3$ V. $V_{ee1} = 0$ V, $V_{g1} = -10$ V, and $P_\mu = 30$ W.

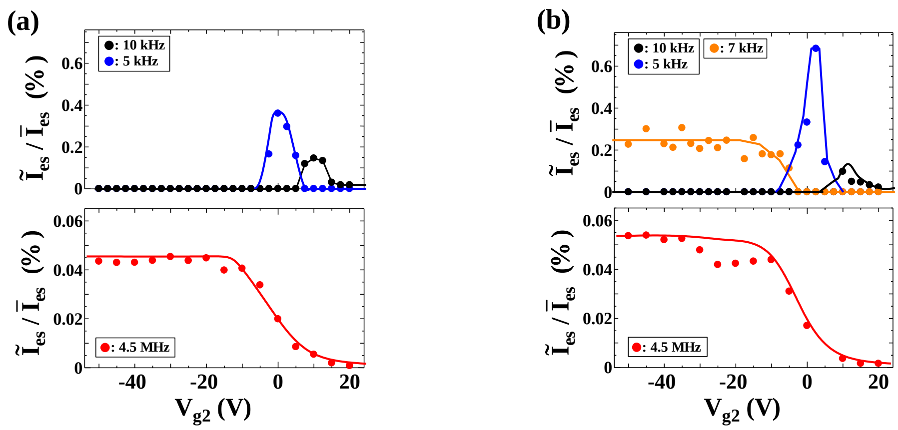

Fig. 5. Normalized amplitudes $\tilde{I}_{es} / \bar{I}_{es}$ of fluctuation with low and high frequency as a function of V_{g2} for (a) $V_{ee2} = 0$ V, and (b) $V_{ee2} = -3$ V. $V_{g1} = -10$ V, $V_{ee1} = 0$ V, and $P_{\mu} = 30$ W at r = –1.5 cm.

= –10 V and (b) $V_{ee1} = 0$ V, $V_{ee2} = -3$ V, $V_{g1} = -10$ V. In Fig. 5(a), the low-frequency (about 5 and 10 kHz) and high-frequency (4.5 MHz) fluctuations are observed, however, only the high-frequency fluctuation amplitude is varied in a same manner as the ETG which is shown in Fig. 2(b). In Fig. 5(b), on the other hand, the new low-frequency (7 kHz) fluctuation which is originally caused by the E×B shear is observed and the fluctuation amplitude increases similarly to that of the high-frequency fluctuation driven by the ETG. This low-frequency fluctuation is considered to be enhanced by the coupling to the ETG mode.

IV. Conclusion

A novel method superimposing the high-temperature electrons on the low-temperature electrons has developed to form and control the ETG in a magnetized plasma. The formed ETG is found to excite the high-frequency fluctuation, i.e., ETG mode, and it is clarified that the ETG mode enhances the low-frequency fluctuation originally caused by the E×B shear through the coupling between the high and low frequency fluctuations.

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