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Effects of Gas Pressure on Electron Temperature Gradient Mode in Magnetized Plasma

磁化プラズマ中電子温度勾配モードに対するガス圧力の効果

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An electron temperature gradient (ETG) is formed by superimposing an electron cyclotron resonance (ECR) plasma, which passes through two different-shaped mesh grids, upon low-temperature thermionic electrons. The formed ETG is found to excite a high-frequency fluctuation, and furthermore, the excited fluctuation is affected by argon gas pressure P_{Ar}. The normalized amplitude of the fluctuation attains the largest value at P_{Ar} = 0.1 mTorr, which is determined by the competition between the electron temperature gradient and density gradient with different dependences on the gas pressure.

1. 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. Although there are some earlier theoretical [3,4], 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.

Therefore, a basic experiment on the ETG mode is urgently desired. Based on these backgrounds, the aim of this work is to control the ETG by using a novel plasma synthesis method superimposing high and low temperature electrons in a basic plasma device and to experimentally investigate the ETG mode with changing the plasma parameters [7].

2. Experimental Apparatus and Method

The 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 generated from a tungsten (W) hot plate set at the end of the machine. The argon (Ar) gas and a microwave (frequency 6 GHz and power P_μ = 10–100 W) are used to control the electron density and temperature in the experimental region. Two different-shaped stainless mesh grids 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 [7]. A Langmuir probe is used to measure radial profiles of plasma parameters at $z = 0$ cm in the experimental region.

3. Experimental Results and Discussion

Figure 2(a) shows ΔT_e (ETG), which is the difference of the electron temperature between the central region (r = 0 cm) and peripheral region (r = 2 cm), as a function of V_{g2}. It is found that the amplitude of the ETG gradually increases with a

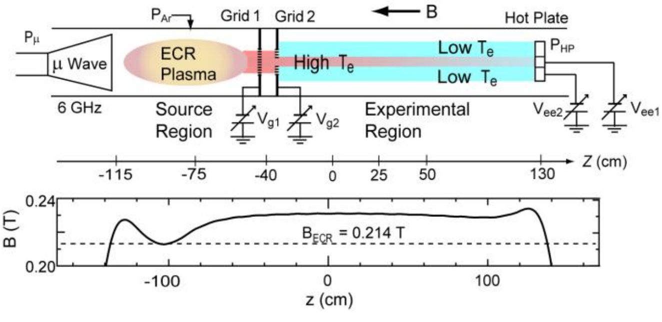

Fig. 1. Schematic diagram of the experimental apparatus and an axial profile of the magnetic field strength.

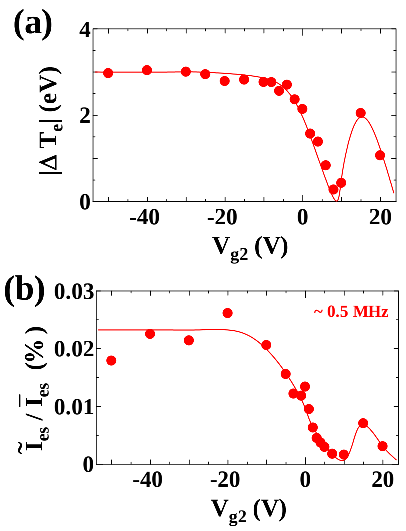

Fig.2. (a) Electron temperature gradient ΔT_e and (b) normalized amplitudes $\tilde{I}_{es} / \bar{I}_{es}$ of high-frequency fluctuation in the central and peripheral regions as a function of V_{g2} for V_{g1} = –5 V, V_{ee1} = 0 V, V_{ee2} = 0 V, and P_μ = 70 W.

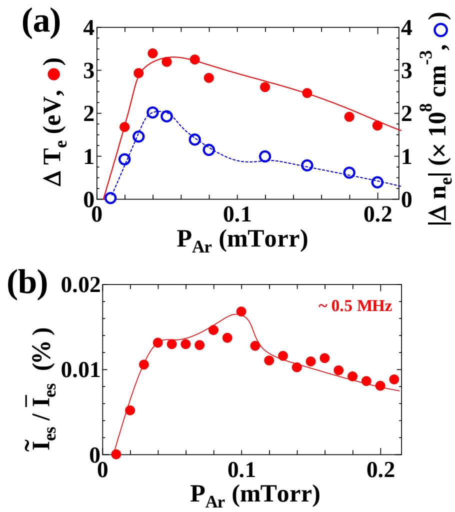

Fig.3. Pressure dependences of (a) the Electron temperature gradient ΔT_e and density gradient Δn_e, and (b) normalized amplitudes $\tilde{I}_{es} / \bar{I}_{es}$ of high-frequency fluctuation for V_{g1} = –5 V, V_{g2} = –30 V, V_{ee1} = 0 V, V_{ee2} = 0 V, and P_μ = 70 W.

decrease in V_{g2} and saturates around V_{g2} = – 20 V. When the ETG is formed, the high-frequency fluctuation is observed to be excited. In Fig. 2(b), dependence of the normalized amplitude $\tilde{I}_{es} / \bar{I}_{es}$ of the fluctuation with frequency of ~0.5 MHz on V_{g2}, is presented. The normalized amplitude varies in a same manner as the ETG. Therefore, it is clear that the high-frequency fluctuation is ETG mode.

Figure 3 shows (a) the electron temperature gradient ΔT_e and density gradient Δn_e, and (b) the normalized amplitudes $\tilde{I}_{es} / \bar{I}_{es}$ of the high-frequency fluctuation as a function of argon gas pressure P_{Ar}. When the pressure is increased, the ΔT_e and Δn_e initially increase. This phenomenon is caused by the increase in the density of the high temperature electrons generated by the ECR discharge with an increase in P_{Ar} until 0.04 mTorr. However, for P_{Ar} > 0.04 mTorr, the ΔT_e and Δn_e gradually decrease, which is affected by the electron-neutral collisions, i.e., the electron mean free path is almost the same as the plasma length. As seen in Fig. 3(b), the normalized amplitude of the high-frequency fluctuation becomes large until P_{Ar} = 0.04 mTorr and gradually decreases for higher P_{Ar} similarly to the tendency of ΔT_e. However, the normalized amplitude of the high-frequency fluctuation becomes large from P_{Ar} = 0.05 to 0.1 mTorr, where the Δn_e suddenly decreases with an increase in P_{Ar}. Since the appropriate ETG driving parameters are $\eta_e = d\ln T_e / d\ln n_e$, it is considered that the different change of ΔT_e and Δn_e for the gas pressure causes the largest value of the normalized amplitude of the high-frequency fluctuation around 0.1 mTorr.

4. Conclusion

A novel method superimposing the high-temperature electrons on the low-temperature electrons has been 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 the normalized amplitude of high-frequency fluctuation becomes the largest value when the Ar gas pressure is 0.1 mTorr. The gas pressure yielding the maximum fluctuation amplitude is determined by the competition between the electron temperature gradient and density gradient with different dependences on the gas pressure.

Acknowledgments

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