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The Effect of High Energy Electron on the Wave Length of Electron Bernstein Wave
電子バーンシュタイン波の波長に対する高エネルギー電子の影響

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It was observed that the wavelength of Electron Bernstein Waves(EBWs) in Mini-RT device is longer than the length theoretically calculated. A reason which can be surmised is the effect of existence of high energy electrons. Therefore the electron energy distribution was measured by a single probe and the existence of high energy electron was confirmed. Furthermore the effect on the wavelength of EBWs was calculated numerically. The result showed that high energy electron must be affect the wave length of EBWs in Mini-RT.

1. Introduction

Requirements to realize nuclear fusion power plant are high density and temperature of plasma. One of the way to heat fusion plasma is using Radio Frequency. However, in the high density plasma, normal electromagnetic wave can not propagate, whereas Electron Bernstein Waves (EBWs) can do without a limit of density. Therefore using EBWs to heat high density plasma is considered and it is important to acquire the knowledge about EBWs.

In order to investigate characteristics of EBWs, the direct observation of EBWs has been conducted by using the internal coil device Mini-RT. The experiments suggested that the wavelength of EBWs was longer than the theoretically calculated length. One possible reason is the existence of high energy electrons. Numerical calculation of the EBWs' dispersion also suggested the effect of high energy electrons on the wavelength. In order to confirm the existence of them, the electron energy distribution function must be measured in Mini-RT. Hence, a single probe was introduced into Mini-RT.

2. Principle of Measurement

In the region of electron repulsion, the electron current into single probe is expressed as [1]

$$I_{\mathrm{e}} = \frac{eN_{\mathrm{e}}S_{\mathrm{p}}}{\sqrt{8m_{\mathrm{e}}}} \int_{E_{\mathrm{c}}}^{\infty} \left(1 - \frac{E_{\mathrm{c}}}{E}\right) \sqrt{E} \cdot F(E)\, dE \qquad (1)$$

where $F(E)$ is the electron energy distribution, e, m_{e}, N_{e} and E are the electric charge of electron, the mass of electron, the density of electron and the energy of electron, respectively. S_{p} is the area of the probe and E_{c} is the lowest energy of electrons which can reach the probe. Replacing E by eV and differentiating I_{e} twice by V, which is defined as $V = V_{\mathrm{s}} - V_{\mathrm{p}}$ (V_{s}: space potential V_{p}: probe potential), gives

$$\frac{d^2 I_{\mathrm{e}}}{dV^2} = \frac{e^2 N_{\mathrm{e}} S_{\mathrm{p}}}{4} \sqrt{\frac{2e}{m}} \cdot \frac{F(eV)}{\sqrt{V}} \qquad (2)$$

Therefore $F(E)$ is obtained by measuring current flowing into probe with sweeping the potential of the probe and differentiating the current by the potential. If $F(E)$ is Maxwellian distribution, (2) becomes

$$\frac{d^2 I_{\mathrm{e}}}{dV^2} = N_{\mathrm{e}} \frac{e\sqrt{e}\, S_{\mathrm{p}}}{\sqrt{2\pi m T_{\mathrm{e}}^3}} \cdot \exp\left(-\frac{V}{T_{\mathrm{e}}}\right) \qquad (3)$$

where T_{e} is the electron temperature in unit of [eV]. As it is obvious from the equation, $\ln(d^2 I_{\mathrm{e}}/dV^2) \propto -V/T_{\mathrm{e}}$. It indicates that electron temperature can be obtained from the gradient of natural logarithms of $d^2 I_{\mathrm{e}}/dV^2$. Besides the electron density is also given after the electron temperature is calculated.

The differentiation of measured data is difficult, because the noise with high frequency can be easily amplified. Thus, it is needed to pay attention to prevent amplification of noise. There are three ways to differentiate the signal, which are numerical differentiation, circuit differentiation and differentiation using Fourier transform. Numerical way suppresses noise by smoothing or averaging data. Differentiation circuit uses low-pass filters for denoising. Fourier transform uses a window

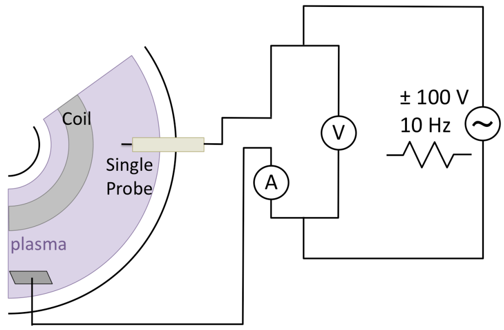

Fig.1.The system of the single probe

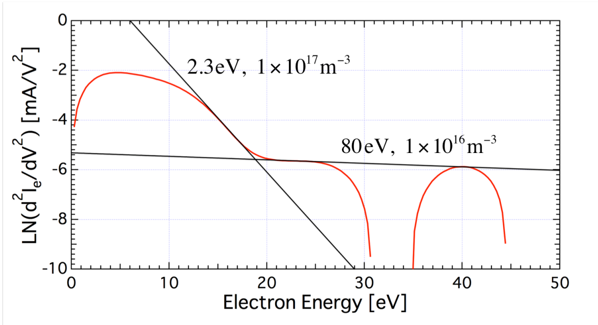

Fig.2.Differentiation of electron current

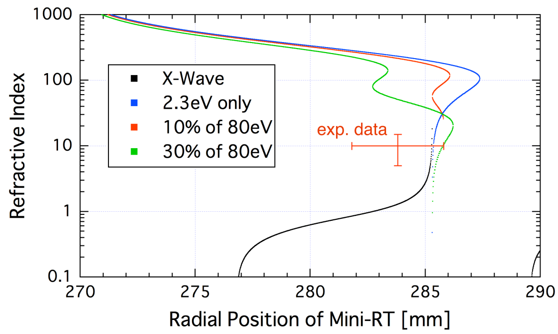

Fig.3.The dispersion of EBW

function to cut out noise. The merits and demerits of each way are written on ref.[2]. Numerical way was applied in this experiment because of its simplicity.

3. Method

The Mini-RT device has an internal coil and plasma is confined by the magnetic field. In the device, the hydrogen plasma is produced by a microwave with a frequency of 2.45 GHz.

The single probe installed is made of tungsten rod which has 0.8 mm in diameter. It is covered by ceramic tube except 5 mm of its head. The system of the single probe is shown in Fig.1. The potential applied on the probe was sweeped by a unit of an amplifier and a function generator as a form of a triangular wave with an amplitude from -100 V to +100 V. The frequency was 10 Hz. Approximately 0.02 T of a magnetostatic field was applied at the measurement point by the internal coil made of high-temperature superconductor. Since electron larmor radius is bigger than radius of the probe in this region, the theory of single probe of unmagnetized plasma can be used. The signal obtained was smoothed and differentiated by using an analysis software, Igor (Co.WaveMetrics).

4. Result

The result is shown on Fig.2. The horizontal axis is the energy of electrons and the vertical axis is natural logarithm of differentiation of measured current. Though it is not following Maxwellian distribution in lower energy region, it shows that there are electrons with two different temperatures, 2.3 eV and 80 eV. The densities of electrons with each temperature are 1×10^{17} m^{-3} and 1×10^{16} m^{-3}, respectively, which are calculated by equation (3). It indicates that about 10 % of electrons have high energy of 80 eV.

Under this condition, the wavelength of EBWs can be calculated and the result is shown on Fig.3. The horizontal axis is the radius position from the center of Mini-RT. The temperature is assumed to be uniform and density gets lower following the radius position becomes large. The vertical axis is refractive index of EBWs calculated from the dispersion relation. Black and Blue lines are dispersion of extraordinary waves and dispersion of EBWs with only 2.3 eV electrons, respectively. Red line corresponds to the case of Fig.2, which has 90% of 2.3 eV electrons and 10 % of 80 eV electrons. Green line shows the dispersion when the 30 % of electrons have 80 eV. It shows the 80 eV electrons contribute to make the wavelength of EBWs longer. However, the condition measured this time does not give an enough explanation for the long wavelength of EBWs. As green line indicates, more electrons must have high energy. In further investigation, some artifices such as other differentiation ways must be used to find high energy electrons.

References

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[2] S.Watanabe: Study on the Electron Energy Distribution Function Measurement Using an Electrostatic Probe in Linear Plasma Device, Master thesis of Univ. of Tokyo, (2014).