*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-4.219 (2009)*

Directly Verification of an Electron Bernstein Wave Heating in the Internal Coil Device Mini-RT

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1. Introduction

In Mini-RT, which has a magnetically levitated high temperature superconductor coil, overdense plasma, i.e. plasma density exceeds cut-off density of electromagnetic waves, was observed [1]. Plasma production and heating in Mini-RT is achieved only by the radio frequency wave with 2.45GHz. Therefore, overdense plasma production suggests that plasma heating which overcomes density limit seems to be taken place. An objective of this research is to identify the mechanism of overdense plasma production and heating.

Electron Bernstein Wave (EBW), which is an electrostatic wave, is free from this density limit, and can propagate into a so-called overdense plasma [2]. Therefore, EBW heating and current drive play important roles in many torus devices [3-5]. Usually, EBW can be excited by mode-conversion from electromagnetic wave in plasma. Thus, a direct detection of the EBW at the outside of plasma is not available. The detection of mode-converted EBW in plasma is tried by using ECE diagnostics, which enable the evaluation of mode-conversion from outside of plasma [6]. On the other hand, we developed the measurement system of an ECRF electric field at the inside of the plasma for direct detection of an EBW [7,8]. This system enables one to obtain the amplitude and phase profiles of ECRF electric field experimentally.

2. Experiments on wavelength and phase identification

Experimental setup

We adopted interferrometry for the measurement of ECRF electric field in plasma. Figure 1 shows the schematic diagram of interferometry system [8]. We inject a diagnostic microwave with a frequency different from that of the plasma production and heating, and measure the wave characteristics of this diagnostic microwave by inserting probing antennas inside the torus plasma. The microwave of 1~2 GHz with a power level of ~ 10 W is launched from excitation antennas. Since 2.45 GHz ECH power for plasma production and heating is around 2.5 kW, this diagnostic microwave does not affect to plasma density and temperature. One has to lock the difference of the frequency between LO1 and LO2 to 10

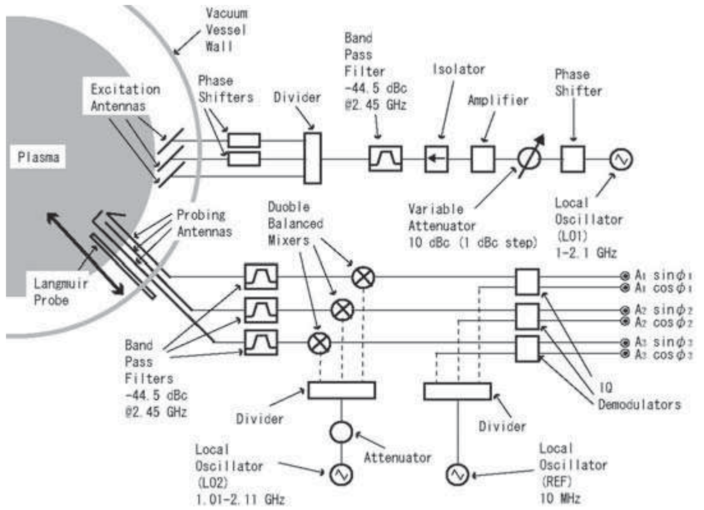

Fig. 1 Heterodyne method has been adopted, and IQ demodulators give cosine and sine (real and imaginary part) of signals. Band Pass Filters (BPFs) prevent penetration of microwave for heating.

MHz. By using an IQ demodulator, we can obtain two signals $A\cos\phi$ and $A\sin\phi$, where A and ϕ are the amplitude of signal detected by a probing antenna and its phase, respectively. In addition, by changing a frequency of the diagnostic microwave, we can investigate wave characteristics for various plasma conditions such as overdense and low-density plasmas for the same discharge condition.

Experimental Results

The Microwave with the frequency of 1 GHz is injected into the plasma with the peak electron density of ~7×10^{16} m^{-3}, and relatively short-wavelength signal is observed in plasma around last closed flux surface, as shown in Fig.2. Evaluated wavelength is ~20 mm, i.e. it corresponds to ~15 of refractive index. Figure 2 shows the cosine and sine components of electrostatic ECRF field with respect to radial position, as well. Wavelengths of electrostatic component are much shorter than those of electromagnetic ones, which are comparable to the wavelength in vacuum, e.g. 300 mm for the 1.0 GHz injection.

Figure 3 shows the phase profiles of each component of Fig. 2. We have confirmed the phase reversal around the UHR. The gradient of phase corresponds to the direction of a phase velocity. If one assumes the direction of group velocity, i.e. that of energy flux, is inward of the device, experimental results show that the measured short-wavelength signal is the backward wave.

EBW is excited around UHR, which is determined from density and magnetic field profiles. In the Mini-RT device, plasma confinement region can be changed easily by applying levitation coil current, i.e. levitation coil current creates separatrix in vacuum vessel so that it determines last closed flux surface. This makes it possible to move the steep density gradient location. Figure 4 shows density profiles and the electrostatic components of ECRF electric field. Short-wavelength region moves outward of vacuum vessel as spreading the plasma confinement region. Therefore, these results suggest the excitation of EBW around

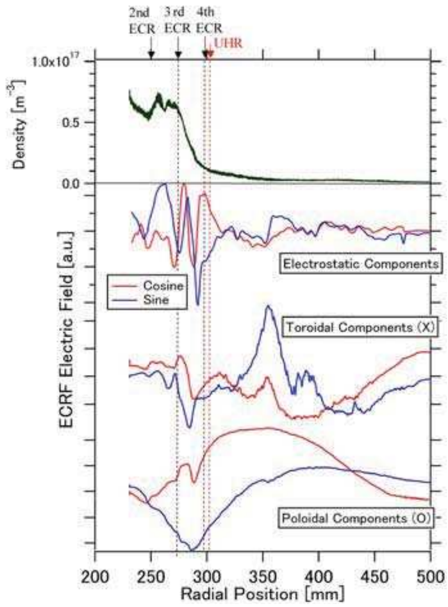

Fig. 2 Typical ECRF electric field measurement results with separatrix condition. In this case, the frequency of injected microwave was 1.0 GHz.

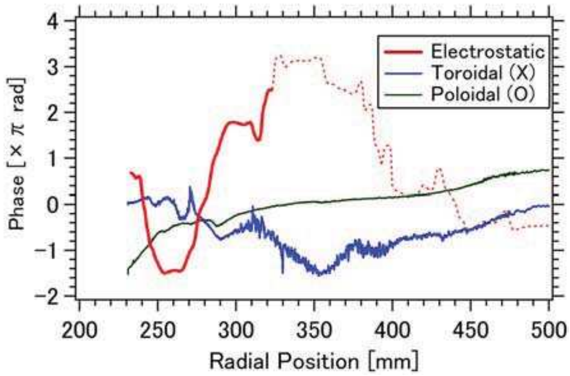

Fig. 3 Phase profiles of each component of an ECRF electric field.

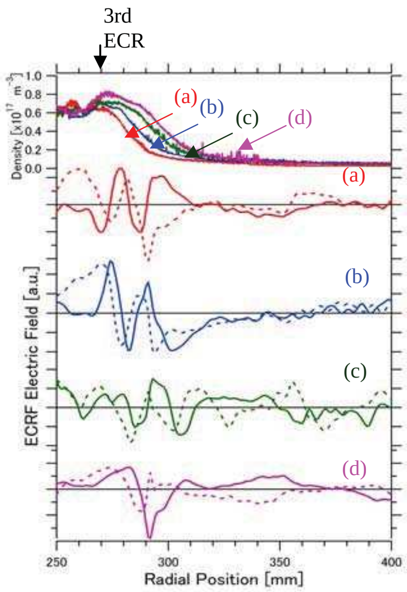

Fig. 4 Density profiles and electrostatic components of ECRF electric field. Short-wavelength region moves with density profile.

UHR. In addition, short-wavelength signals have been damped near the harmonic electron cyclotron resonance (ECR) layer, e.g. in this case, 3rd harmonic ECR around radial position R=270 mm [7,9]. Strong damping at harmonic ECR is one of the most crucial characteristics of EBW. Furthermore short-wavelength microwave exists at the evanescent region of cold (electromagnetic) waves. From those things, directly detecting of EBW in torus plasma is suggested. However, wavelengths of them do not quantitatively agree with that given by dispersion relation of EBWs [7,9,10]. Further experimental and numerical studies, e.g. hot electron effect and density gradient effect, are expected [10].

3. Experiments on group velocity measurement

Experimental setup

By injecting a pulse signal and detecting the spatial dependence of arrival time of it, one can obtain the group velocity experimentally [11]. In order to carry out the injection of the ultra-short pulse microwaves, e.g., around 10 nanoseconds, we used a PIN diode switch which opens during the period that the gate signal exceeds a threshold voltage. Figure 5 shows the schematic diagram of the pulse injection experiments. The signal detected by an

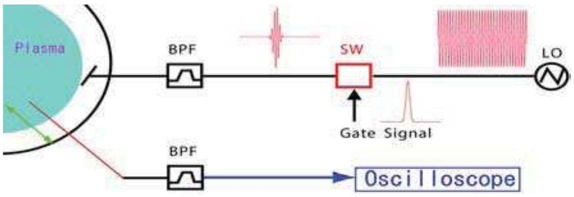

Fig. 5 Schematic drawing of pulse injection experiments.

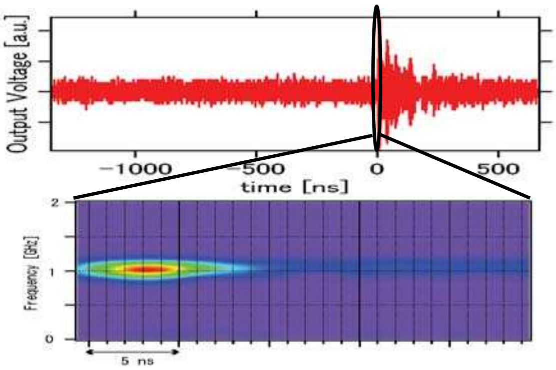

Fig. 6 Preliminary result of pulse arrival time.

antenna is collected to an oscilloscope with 20 GS/s of sampling rate, which directly enables one to observe a waveform of microwave with frequency of the order of GHz.

Preliminary Results

Figure 6 shows a preliminary result of a pulse arrival time detection. The signal is analysed by frequency-time analysis. Although the pulse width is around 10 ns, i.e. there are only 10 cycles in an injected pulse, frequency profile is well localized around the injected frequency, i.e. 1.0 GHz. Detailed measurements, e.g. special profile of pulse arrival time, are future works.

4. Summary

Direct measurement of ECRF electric field was carried out to identify the mechanism of overdense plasma production in Mini-RT, and characteristics on the EBW such as short-wavelength, excitation at UHR, damping at harmonic ECR and backward propagation were experimentally observed. Quantitatively approaches of group velocity and wavelength are future works.

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