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Experimental Verification of the Excitation and Propagation of Electron Bernstein Waves via three Excitation Scenarios in the Internal Coil Device Mini-RT

内部導体装置Mini-RTにおける3つの励起方法による電子バーンスタイン波の励起・伝搬に関する実験的検証

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The EBWs have several characteristics that are favorable for heating high beta plasmas, i.e., the EBWs have no cutoff density. To verify the excitation of the EBWs in dipole confinement plasmas, wave characteristics in overdense plasma was directly measured with probing antennas. Three EBW excitation scenarios have been applied to the device, i.e. FX-SX-B, O-X-B and SX-B conversion. The experimental results showed many properties of mode conversion at the UHR; short wavelength, electrostatic mode, longitudinal polarization, and backward wave mode. These drastic changes of wave characteristics support that the injected waves reach to the UHR and converted into the EBWs.

1. Introduction

The Electron Bernstein Waves (EBWs) have no cutoff density and plural energy absorption layers. Therefore, EBWs are expected to be an effective method for heating and current drive of high density plasma, and enthusiastic researches have been theoretically and experimentally carried out in spherical torus and helical plasmas [1,2]. Since the EBWs cannot propagate in vacuum, it is necessary to convert an electromagnetic wave into an electrostatic mode inside the plasma. Three excitation scenarios of EBWs are well known, i.e. 1) Perpendicular injection of X waves from low field side, 2) Oblique injection of O waves from low field side and 3) Perpendicular injection of X waves from high field side. Their conversion efficiency and the most suitable scenario depend on the configuration and parameters of the plasma.

This work is concerned with waves in torus plasma confined by dipole magnetic field, and an experimental verification of EBWs through the direct measurement inside plasmas is explored for three excitation scenarios of EBWs in the internal coil device Mini-RT.

2. Experimental Setup

The Mini-RT device was constructed to confine high beta plasma with planetary magnetic field [3], and the magnetic field is formed by two coils; one is an internal coil constructed with a high temperature superconductor (HTS) and the other

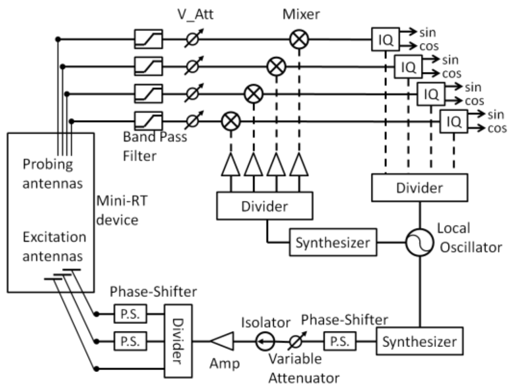

Fig.1. Schematic diagram of diagnostics

is levitation coil made with copper. Magnetic configurations are determined by the ratio of magnetomotive force of those two coils, so that one can change the plasma confinement region sassily by adjusting levitation coil current. Plasmas in the Mini-RT device are produced and heated by ECH with continuous microwaves at the frequency of 2.45 GHz with a power of 2.5 kW.

In the device, waves at frequencies lower than 2.45 GHz are injected to diagnose wave characteristics in overdense plasmas. The plasma produced by 2.45 GHz microwaves acts as an overdense plasma with respect to lower frequency diagnostic microwaves. In this study, to investigate three different scenarios for the mode conversion to EBWs, three types of EBW excitation antennas are installed in the vacuum vessel. To examine the mode conversion of waves from electromagnetic to

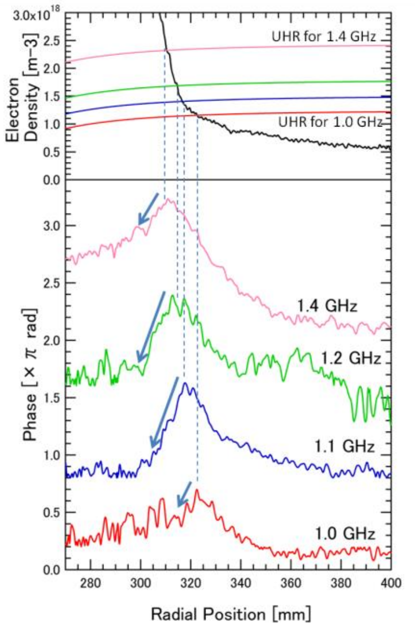

Fig.2. Phase profiles of electrostatic component (longitudinal wave mode) for several frequencies.

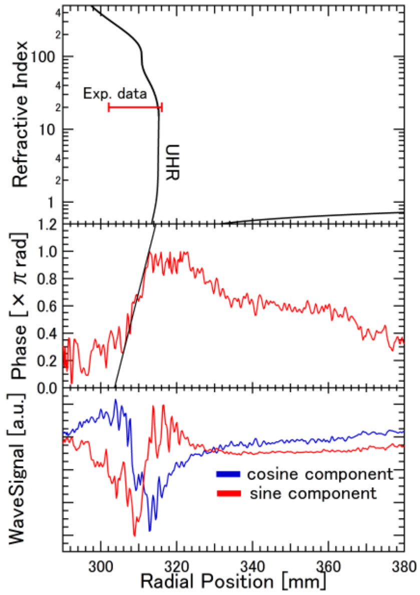

Fig.3. Comparison between refractive index profile and location for excitation of short wavelength mode.

electrostatic mode, the electromagnetic and electrostatic components are measured simultaneously by probing antennas inserted directly in to the plasmas. Figure 1 shows a schematic diagram of the diagnostics. Detected signals are sent to the mixer and modulated by IQ demodulators. The IQ demodulator outputs time –independent signals, which have information of amplitude and phase as a function of the position of probing antennas.

3. Experimental Result

The experimental results show many properties of mode conversion from electromagnetic to electrostatic. In the FX-SX-B conversion, Electrostatic short-wavelength mode has been observed near the Upper Hybrid Resonance (UHR) layer by comparing signals between magnetic loop antennas and electrostatic probing antennas. The wavelength of this mode is about 1.5 ~ 2.0 mm and a reversal of the phase gradient around the UHR is confirmed. This reversal indicates a change in the direction of the phase velocity. Figure 2 shows the spatial profiles of the phase for several frequencies of diagnostic microwaves, and phase reversals appear around the UHR region in all cases. We can see that the radial position of the phase reversal is slightly shifting to the higher density region, as the frequency of the diagnostic wave is increased. This is corresponding to the shift of the UHR region. Figure 3 shows the comparison between refractive index, waveforms and phase profiles for 1.1 GHz diagnostics wave. The waves with short wavelength mode have been observed in the region of the mode conversion, and the refractive index experimentally observed seem to be in agreement with that of the UHR region.

In the O-X-B conversion, the optimum injection angle is existing for the incident microwave. Experimentally it has been observed that the wave characteristics strongly depend on the injection angle, and the waves with the short wavelength have been observed only at certain injection angle. This suggests the existence of the optimum injection angle for exciting the EBW in the O-X-B conversion scenario.

In the SX-B conversion, operation window for the density is quite limited, because the no L-cutoff condition should be satisfied in the wave propagation region. When this condition has been satisfied, the short wavelength mode has been experimentally observed, although the phase reversal has not been identified.

In all of the three conversion scenarios, experimental results show many characteristics of mode conversion from electromagnetic waves to the EBWs, except that their wavelength are about one order larger than theoretical one. Although we might not definitively conclude direct observation of the EBWs, we could say that the electromagnetic waves injected outside of torus plasmas reach to the UHR and change their characteristics to the EBWs.

References

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