*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-4.109 (2008)*

Excitation and Propagation of Electron Bernstein Waves in the Internal Coil Device Mini-RT

E. Yatsuka[1], D. Sakata[1], K. Kinjo[1], S. Tanaka[1], J. Morikawa[1], Y. Ogawa[1]
[1]*University of Tokyo, Kashiwa Chiba, Japan*

Electron Bernstein Wave (EBW) heating is promising method for high beta plasma heating because this wave has no density limit for propagation and can propagate perpendicular to magnetic field surface. However EBW is an electrostatic mode having wavelength comparable to electron Larmor radius [1]. Therefore it is important issue to investigate excitation, propagation and damping of EBW in plasma. Recent experimental and numerical studies show the possibility of effective heating and current drive by EBWs [2-5].

The goal of this study is to identify EBWs in plasma. We inserted antennas into plasma and observed Electron Cyclotron Range of Frequency (ECRF) electric field.

Magnetic Configuration and Experimental Methods

This study was carried out with dipole magnetic field in the internal coil device Mini-RT [6] in which aim to confine high beta plasma with self-organized states of flowing plasma [7]. In order to investigate the effect of magnetic field configuration, we can change plasma confinement region by applying levitation coil current, which is placed above vacuum vessel. Figure 1 shows the typical magnetic configuration, solid and dotted lines denote magnetic field lines and contours of magnetic field strength, respectively. Unlike tokamaks or stellarators, dipole magnetic field has very steep magnetic filed strength variation, i.e. $B \propto r^{-3}$.

Extraordinary wave propagating nearly perpendicular to magnetic field was launched from the low field side, which is one of the most effective methods for excitation of EBW in plasma via mode-conversion. We used three dipole antennas for launching, whose phases are matched. Element lengths of these antennas correspond to half-wavelength for 1.5 GHz vacuum emission. Antennas for probing ECRF electric fields were inserted in plasma and were movable radially. Figure 2 shows the diagram of ECRF electric field measurements. In order to evaluate amplitude and relative phase, we used IQ demodulator.

Dispersion Relation

Electron Bernstein Waves are excited around Upper Hybrid Resonance (UHR) due to Larmor motion of electron in magnetic field. It is well known that EBWs are almost completely

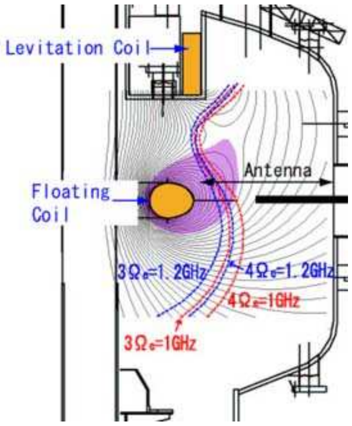

Fig. 1 Magnetic Configuration in the Mini-RT device.

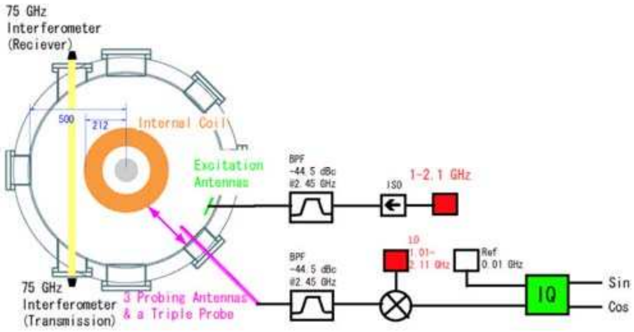

Fig. 2 Diagram of ECRF electric field measurements; we used two dipole antenna (element lengths are 40 mm) and a small monopole antenna (1 mm length).

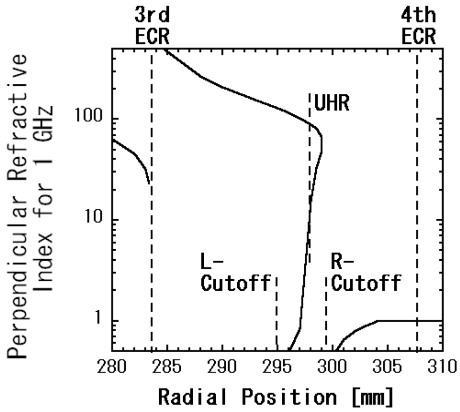

Fig. 3 Profile of perpendicular refractive index for 1.0 GHz injection.

absorbed at harmonic Electron Cyclotron Resonance (ECR) layer because of short-wavelength characteristic.

Therefore we evaluated wavelengths of EBWs by solving dispersion relation of waves in hot plasma [8]. Figure 3 shows the perpendicular refractive index profile with typical configuration of Mini-RT. For simplicity, parallel wavenumber was fixed to zero (perpendicular propagation), and we assumed isotropic Maxwellian of electron distribution function.

Group velocity of an EBW,which corresponds to the direction of energy transfer, is opposite to phase velocity [9,10]. Backward characteristic was observed in Mini-RT with relatively short-wavelength (refractive index is around 10) [11].

Profiles of ECRF electric field

We observed relatively short-wavelength signal in plasma around last closed flux surface. Profiles of electron density and electron temperature were measured by Langmuir probe, and ECRF electric field is measured by antennas. Langmuir probe and antennas are movable radially in plasma simultaneously. We launched 1.0 GHz diagnostic microwave, whereas plasma was produced by 2.45 GHz ECH. As shown in Fig. 4, peak electron density is ~7×10^{16} m^{-3}, i.e. overdense for 1.0 GHz, and underdense for 2.45 GHz. Plasma is not perturbed so much during insertion of probe and antennas (See line-integrated density measured with 70 GHz interferometer in Fig. 4 (f)).

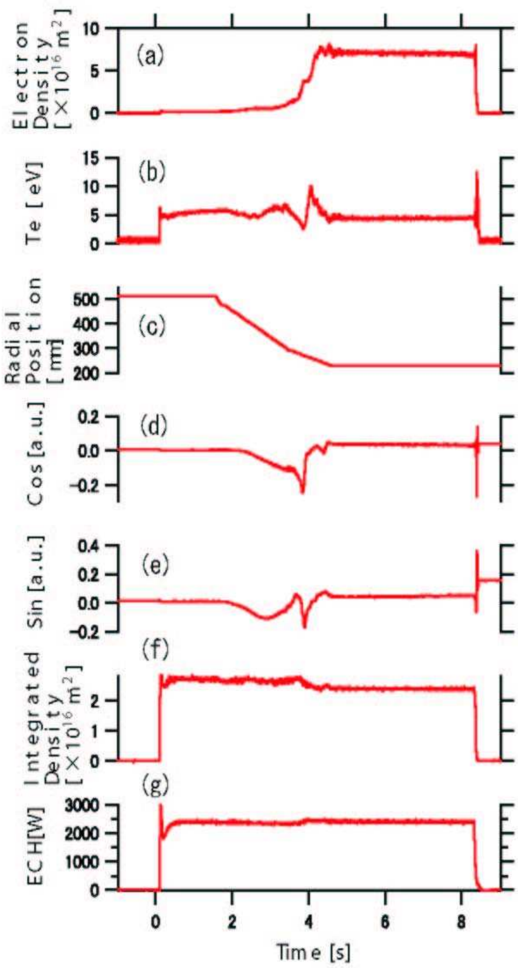

Fig. 4 Typical waveforms of (a) electron density, (b) electron temperature T_e, (c) radial position of antennas and Langmuir probe, (d), (e) Cosine and sine component of electrostatic ECRF electric field (f) line integrated density and (g) ECH power.

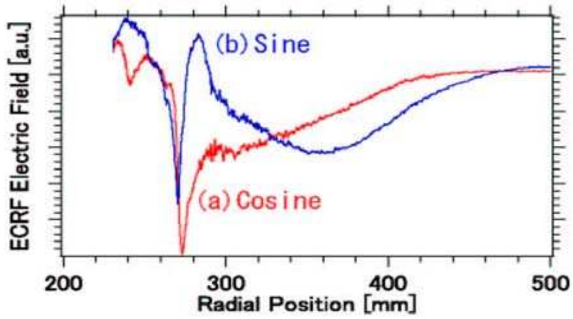

Fig 5 Radial profile of electrostatic ECRF electric field (a)Cosine and (b) Sine component.

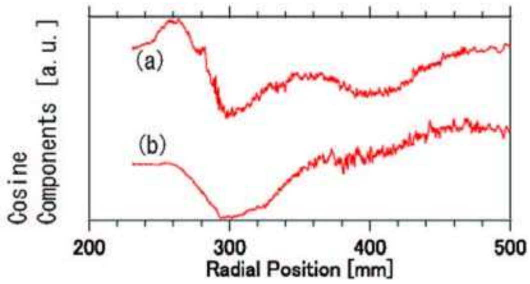

Fig. 6 Waveforms of cosine components of (a) toroidal, extraordinary and (b) vertical, ordinaly wave.

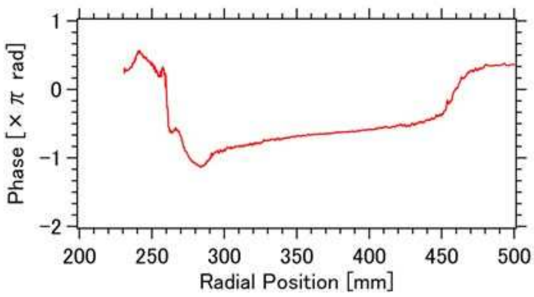

Fig. 7 Relative phase of ECRF electric field.

In Fig. 4 (d) and (e), electrostatic components of ECRF electric field are shown. Co-axial cables are used for antenna. Inner conductor is used for element (1 mm length), and outer conductor is connected to ground. Thus we can measure ECRF temporal electric potential [12]. On the other hands, electromagnetic components can be measured by dipole antenna (40 mm length) sheathed in ceramic glue.

Evaluated wavelength is ~20 mm, i.e. it corresponds to refractive index of ~15. Figure 5 shows the cosine and sine components of electrostatic ECRF field with respect to radial position. We can rotate a probe and antennas, thus two electromagnetic components and an electrostatic component of ECRF electric field, electron density and electron temperature can be measured at an identical chord. Figure 6 shows cosine components of waveforms of electromagnetic components. Wavelengths were longer than the case of electrostatic component. They are comparable to wavelength in vacuum, e.g. 300 mm for 1.0 GHz injection.

The gradient of phase profile denotes the direction of phase propagation. Figure 7 shows the phase profile for the case of Fig. 4. At the region where radial position R>285 mm, phase of ECRF electric field propagates outward of device. On the other hand, at R<285 mm, phase propagates inward of device. As well known, ordinary and extraordinary waves are forward wave, and are able to propagate in vacuum. Therefore, it is suggested that group velocity is outward for the device.

Summary

An electrostatic component and two electromagnetic components of Electron Cyclotron Range of Frequency (ECRF) electric field were measured. We observed relatively short wavelength (~20 mm) signal of electrostatic component. The wavelengths of electromagnetic mode were comparable to that in vacuum. Relative phase profile shows opposite phase propagation between short and long-wavelength region. This suggests the backward characteristic related with Electron Bernstein Waves (EBWs).

References

[1] I. B. Bernstein, Phys. Rev. 109, 10 (1958).

[2] H. P. Laqua *et al.*, Phys. Rev. Lett., 78, 3467 (1997).

[3] A. K. Ram, S. D. Schultz, Phys. Plasmas, 7, 4084 (2000).

[4] G. Taylor *et al.*, Phys. Plasmas 9, 167 (2002).

[5] B. Jones *et al.*, Phys. Rev. Lett. 90, 165001 (2003).

[6] Y. Ogawa *et al.*, J. Plasma Fusion Res. 79, 643 (2003).

[7] S. M. Mahajan, Z. Yoshida, Phys. Rev. Lett., 81, 4863 (1998); Z. Yoshida, S. M. Mahajan, Phys. Rev. Lett., 88, 095001 (2002).

[8] T. H. Stix, *Waves in Plasmas* (American Institute of Physics, 1992) p. 257-262.

[9] F. W. Crawford *et al.*, J. Geophys. Res. 72, 57 (1967).

[10] S. Puri *et al.*, J. Plasma Phys. 9, 89 (1973).

[11] E. Yatsuka *et al.*, Plasma and Fusion Res. 3, 013 (2008).

[12] S. Gruber and G. Bekefi, Phys. Fluids, 11, 122 (1968).