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Observation of electron cyclotron waves emitted via mode conversion processes and analysis of their propagation characteristics

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The mode conversion process between the electrostatic and the electromagnetic waves commonly occurs both in experimental and space plasmas. The characteristics of the mode conversion process have been analyzed based on the plane wave theory. However, the actual waves are not necessarily plane waves. For example, if the source region of the emissive wave is highly localized, or the launching antenna of the wave has a directivity, we have to consider the effect of geometry of the wave surface to analyze the wave propagation direction, mode conversion rate, power absorption, and so on with introducing the wave optical analysis [1]. The electron Bernstein wave (EBW) is an electrostatic wave in the magnetized plasma and damped when the electron cyclotron resonance condition is fulfilled. Different from the electromagnetic wave, the EBW can propagate without density limit, on the other hand cannot propagate in the free space. When the electron density around the electron cyclotron resonance (ECR) is more than the cutoff density of the electron cyclotron resonance frequency wave, the thermally emitted waves in the electron cyclotron frequency range propagate as the EBW in the plasma. If the EBW accesses the upper hybrid resonance (UHR), the mode conversion to the electromagnetic wave occurs and we can observe the wave with use of the antenna installed in the vacuum region in the experimental device.

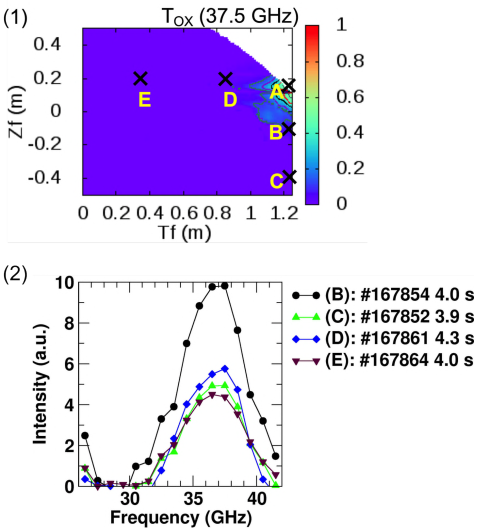

Figure 1: (1) Distribution of the O-X mode conversion rate (T_{OX}) on the antenna target plane. T_{OX} is calculated based on the plane wave theory. (2) Frequency spectra measured by radiometer. The aiming direction of the antenna was changed as indicated the above graph. Because the view-line hits the vacuum vessel wall in the case of (a), the spectra is not shown here.

In the large helical device (LHD), the emissions of the electron cyclotron frequency range were observed when the electron density around the ECR exceeded the plasma cutoff density. The thermally emitted EBW is the possible source. Via the double mode conversion from the EBW to the extraordinary (X) mode at the upper hybrid resonance (UHR) and from the X mode to the ordinary (O) mode near the plasma cutoff, the wave originating from EBW can be converted to the electromagnetic wave propagating in the free space. As shown in Figure 1, the intensity decreases as the aiming direction of the detection antenna departs from the optimum that is predicted based on the plane wave theory. However, the decrement is less than that predicted by the plane wave theory. Because the quasi optical mirror antenna is used as the detection antenna the wave surface is not plane and the effect of the finite width on the X-O mode conversion characteristics should be taken into account.

We have analyzed the wave propagation from the X-O mode conversion region to the plasma boundary with using TASK/WF2D code as the reversal problem of the O-X mode conversion in the two-dimensional system. Firstly, the O-X mode conversion rate (T_{OX}) in the uniform magnetic field has been investigated for waves which have Gaussian beam like electric field profiles. Figure 2 shows T_{OX} plotted as a function of the parallel refractive index ($N_{//}$) for each different case of the launched beam waist size (w_0). Difference from the plane wave theory is enhanced when w_0 is small. With increase of w_0, T_{OX} approaches 1 if $N_{//}$ is optimized.

Reference

[1] H. Igami et al., Plasma and Fusion Research: Vol. 11, 2403098 (2016)

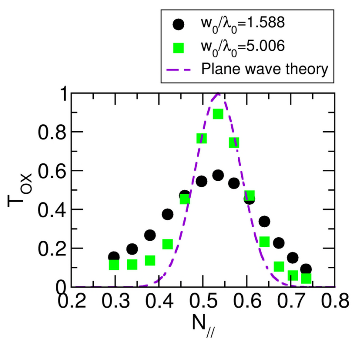

Figure 2: T_{OX} in the uniform magnetic field plotted as function of the parallel refractive index. The cyclotron frequency normalized by the wave frequency (Ω_{ce}/ω) is 0.4.The density scale length normalized by the vacuum wave length (L_n/λ_0) is 7.5 which is much smaller than that of LHD.