Observation of Polarization Reversal and Electron Cyclotron Damping Directly Associated with Obliquely Propagating Left-Hand Polarized Wave

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The polarization reversal from a left-hand (LHPW) to a right-hand polarized wave (RHPW) and the resultant electron cyclotron damping of the LHPW are experimentally observed for the first time. Our experimental results indicate that the polarization reversal arises simultaneously with the conversion of the propagation angle of the wave, in which finite-plasma boundary conditions are considered to be inherent.

Keywords:
polarization reversal, left-hand polarized wave, ECR, oblique propagation, boundary conditions

Electron Cyclotron Resonance (ECR) is considered to be effective against plasma heating, the formation of local confining potential [1], and homogeneous plasma production [2]. In these previous studies, the unexpected damping of a left-hand polarized wave (LHPW) near the ECR point was observed [3,4], and a polarization reversal was theoretically suggested to explain this phenomenon [5]. However, this polarization reversal has not yet been experimentally observed. Thus, the purposes of this work are to verify the polarization reversal experimentally and to clarify the damping mechanisms of the LHPW near the ECR point.

Experiments are performed in the Q_T–Upgrade machine of Tohoku University, where an inhomogeneously magnetized and coaxially bounded plasma is produced by a DC discharge in a low pressure argon gas in the conducting linear vacuum chamber ($n_e \simeq 10^{11}$ cm^{-3}, $T_e \simeq 3$ eV). The characteristic length L_B of the magnetic-field gradient is defined as $L_B = [(1/B)(dB/dz)]^{-1}$ [3]. The LHPW (6 GHz, 150 mW) is selectively launched along the magnetic-field lines (z axis) in the high magnetic-field region by a helical antenna (z = 0 cm), and propagates toward the ECR point (z = 78 cm) in the low magnetic-field region. The wave patterns are obtained with an interference method by using two axially movable antennas that can receive the horizontal E_x and vertical E_y components of the electric field of the waves, respectively.

Figure 1(a) shows the interferometric wave patterns of E_x and E_y for L_B = 0.629 m, which are observed at a radial center of the plasma column. The long (LW) and

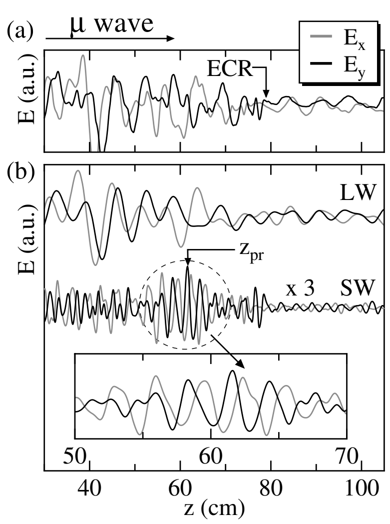

Fig. 1 (a)Observed interferometric wave patterns of E_x and E_y. (b)Long (LW) and short (SW) wavelength components decomposed from Fig. 1(a).

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short (SW) wavelength components, which are decomposed from the observed wave patterns [Fig. 1(a)] using Fourier analysis, are presented in Fig. 1(b). The magnification of the SW in the region of z = 50–70 cm is shown in the inset. The wave patterns of E_x in the LW and the SW are shifted to the left and to the right of the wave patterns of E_y, respectively. From these phase differences between E_x and E_y, the LW and SW are identified as LHPW and right-hand polarized wave (RHPW), respectively. In addition, it is found that the RHPW grows and the LHPW damps around z = 60 cm; namely, the polarization reversal from the LHPW to the RHPW is experimentally observed near the ECR point.

In order to clarify the mechanisms of the polarization reversal, we obtain experimental dispersion relations from LW (closed circle) and SW (open circle) as presented in Fig. 2(a). These experimental results have no agreement with the theoretical dispersion relations for propagation angle $\theta = 0°$, where θ is an angle between a wavenumber vector and magnetic-field lines. This disagreement is considered to be closely related to an oblique propagation of the wave, which originates from the finite plasma and chamber boundaries. Therefore, we attempt to take into account the effect of θ on the theoretical dispersion relations and polarization p ($\equiv iE_x/E_y$), as shown in Fig. 2(a) and (b), respectively. Here, the negative and positive signs of p represent left- and right-hand polarizations, and p = 0, $\pm\infty$ corresponds to linear polarization. As a result, the experimental dispersion relations of the LW and the SW are found to coincide with the theoretical ones for θ = 50° (solid line) and 10° (dashed line), respectively. Furthermore, the polarizations corresponding to the theoretical dispersion curves for θ = 50° and 10° are found to be left-hand and right-hand, respectively, and to agree with the experimentally measured polarizations shown in Fig. 1(b). Consequently, the polarization reversal is believed to arise simultaneously with the conversion of the propagation angle.

This polarization reversal is observed to occur at a certain axial position z_{pr}, which is defined as the position where the amplitude of the RHPW has its maximum value as shown in Fig. 1(b). Dependences of z_{pr} and the normalized frequency ω/ω_{ce} at $z = z_{pr}$ on L_B are presented in Fig. 3. z_{pr} gradually shifts to the upper region of propagation with an increase in L_B, however, ω/ω_{ce} is almost constant ($\simeq$ 0.84) at these positions. This constant value of ω/ω_{ce} is confirmed to vary when the plasma diameter is changed. In the calculated polarization for θ = 50° shown in Fig. 2(b), p is nearly equal to zero in the case of $\omega/\omega_{ce} \simeq 0.84$. Based on these results, it is found that the polarization reversal can occur when the polarization of LHPW becomes closest to linear polarization, depending on the plasma diameter, or the finite-plasma boundary conditions.

In conclusion, our experiments demonstrate, for the first time, the polarization reversal from the LHPW to the RHPW and the damping of the LHPW near the ECR point. The essential mechanism of the polarization reversal is found to be attributable to the conversion of the propagation angle, which is considered to originate from the finite-plasma boundary conditions.

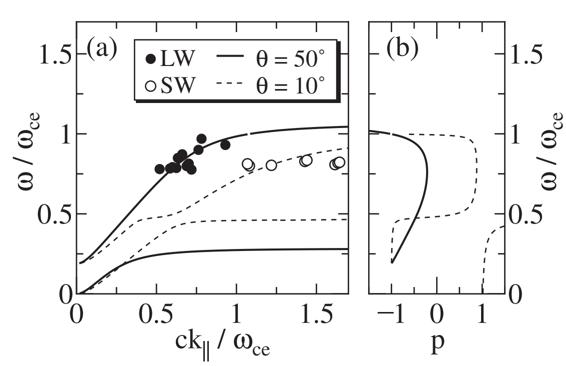

Fig. 2 Theoretical (a) dispersion relations and (b) polarizations for θ = 50° (solid line) and 10° (dashed line), together with experimental dispersion relations obtained from LW (closed circle) and SW (open circle) in Fig. 1(b).

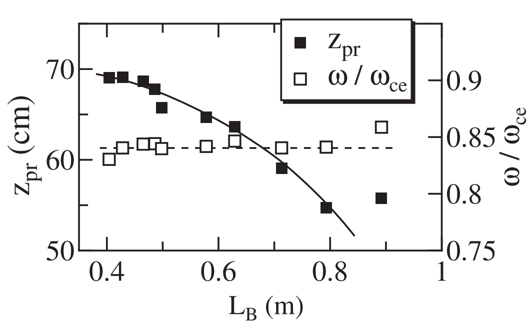

Fig. 3 Dependences of the position z_{pr} where the polarization reversal occurs and normalized frequency ω/ω_{ce} at $z = z_{pr}$ on L_B.

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