Damping Mechanisms of Left-Hand Polarized Wave near the Electron Cyclotron Resonance Point in an Inhomogeneously Magnetized Plasma

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ABSTRACT

Propagation and damping mechanisms of a left-hand polarized wave (LHPW) near the electron cyclotron resonance point are investigated in an inhomogeneously magnetized and bounded plasma. Our experiments demonstrate that the polarization reversal from the LHPW to a right-hand polarized wave occurs at a certain magnetic-field strength, which can be explained by the dispersion relation modified by the boundary condition between a plasma and a vacuum region. In addition, it is observed that a radial profile of the axial component of the electromagnetic-wave power is drastically transformed around the polarization reversal point.

1. INTRODUCTION

Efficient plasma heating and confinement of hot plasmas are absolutely indispensable for realizing a thermonuclear fusion. In recent years, a formation of local confining potential related to electron cyclotron resonance (ECR) has been realized and their physical mechanism has been clarified [1]. In previous studies concerning these issues, the damping of not only a right-hand polarized wave (RHPW) but also a left-hand polarized wave (LHPW), which has been considered not to be theoretically related to ECR, was observed [2, 3]. Although a polarization reversal from the LHPW to the RHPW was theoretically suggested in order to interpret this phenomenon [4], it has not been experimentally evidenced and the detail of this mechanism has not been clarified so far. Thus, the purposes of the present work are to clarify the mechanisms of the LHPW damping near the ECR point and to verify the polarization reversal experimentally.

2. EXPERIMENTAL SETUP

Experiments are performed in the QT-Upgrade Machine of Tohoku University as shown in Fig. 1, where the propagation and damping of the LHPW near the ECR point are investigated in an inhomogeneously magnetized and coaxially bounded plasma. This machine has a cylindrical vacuum chamber about 450 cm in length and 20.8 cm in diameter. The plasma is produced by a direct current discharge between an oxide cathode and a tungsten mesh anode in a low pressure Argon gas (< 10 mPa). The plasma radius is limited to 3 cm by a limiter. The plasma column is terminated on a glass end plate located on the
Fig. 1. Schematic of experimental setup and inhomogeneous magnetic-field configuration.

Under this configuration, the wave propagates toward the ECR point ($z = 78$ cm), satisfying the condition $\omega/\omega_{ce} < 1$. The wave patterns are obtained with an interference method and the spatial profiles of the microwave power are measured by a power meter through axially movable antennas, which can receive the vertical and the axial components of the electric field of the waves, respectively.

3. EXPERIMENTAL RESULTS

Figure 2(a) shows the interferometric wave pattern of the vertical component of the microwave electric field, which is observed at a radial center of the plasma column. The long and short wavelength components, which are decomposed from the observed wave pattern using Fourier analysis, are presented in Fig. 2(b). These long and short wavelength components have been identified as the LHPW and the RHPW, respectively, in our previous paper [5]. The decomposed wave patterns show that the LHPW damps and the RHPW simultaneously grows around $z = 70$ cm. This result means that the polarization reversal from the LHPW to the RHPW occurs near the ECR point, and the LHPW resultantantly damps.

Fig. 2. (a)Observed interferometric wave pattern of the vertical component of the microwave electric field. (b) LHPW and RHPW components decomposed from the observed wave pattern.
In order to clarify the mechanisms of the polarization reversal, the radial profiles of the axial component of the microwave power $P_z$ are measured. The solid lines in Fig. 3 indicate the typical radial profiles of $P_z$ at $z = 29$ cm and 69 cm, which correspond to the regions ahead of and behind the polarization reversal point, respectively. The fitting curves given by $P_z = |A_m J_m(k \perp r)|$ are also drawn in Fig.3 as dashed lines, where $m$ is an azimuthal mode number and $A_m$, $J_m$, and $k \perp$ are an amplitude, Bessel function of order $m$, and perpendicular wave number, respectively. The $P_z$ profile at $z = 29$ cm can be described by the Bessel function of order zero ($m = 0$), while the $P_z$ profile at $z = 69$ cm corresponds to the Bessel function of order one ($m = 1$). This result indicates that the mode conversion from $m = 0$ to $m = 1$ occurs at the polarization reversal point. Since the measured profiles show $P_z = 0$ in the vacuum region (TE mode), the boundary condition between the plasma and the vacuum region is given by $J_m(k \perp r) = 0$ at the plasma edge ($r = 3$ cm). Thus, $k \perp$ can be determined by the fitting curve for the $P_z$ profile at $z = 29$ cm satisfying the above boundary condition, which amounts to about 0.8 cm$^{-1}$ as the experimentally obtained value of $k \perp$.

The dispersion relation modified by the above boundary condition is derived [6] so as to interpret the polarization reversal observed in Fig. 2. Figure 4(a) gives the calculated dispersion relation for $k \perp = 0.8$ cm$^{-1}$, which yields four branches (solid and dashed line), and the experimental values obtained from the LHPW (closed circles) and the RHPW (open circle) as typically presented in Fig. 2(b). The experimental dispersion relation is in good agreement with the calculated one. In addition, the polarization index $p$ ($= |E_r - iE_\phi|/|E_r + iE_\phi|$) is calculated for $m = 0$ mode and given in Fig. 4(b). Here, $0 < p < 1$, $p = 1$ and $1 < p < \infty$ represent right-hand (RHP), linear, and left-hand (LHP) polarization, respectively. The value of $p$ is larger than unity in Fig. 4. (a)Dispersion relation (solid and dashed line) and the experimental values obtained from the LHPW (closed circles) and the RHPW (open circles). (b)Calculated polarization index $p$ corresponding to the dispersion relation.
the high magnetic-field region \((\omega / \omega_{ce} < 0.75)\), or the polarization is left-handed in this region. As the wave approaches the ECR point, the value of \(p\) becomes smaller than unity and gets closer to zero. That is to say, the polarization reversal from the LHPW to the RHPW is theoretically found to occur on the condition of \(\omega / \omega_{ce} \sim 0.75\), and the polarization of this wave is finally converted into the circularly right-handed polarization. As a result, the converted RHPW efficiently damps at the ECR point. This theoretical result has a good agreement with the experimentally observed result that the RHPW starts to grow at \(z = 58\) cm, or \(\omega / \omega_{ce} \sim 0.75\). Thus, it is proved that the dispersion relation modified by the boundary condition explains the observed polarization reversal and its resultant damping of the LHPW. The boundary condition is found to play an important role in the efficient damping and absorption of a electromagnetic wave near the ECR point.

4. CONCLUSION

The propagation and damping of the left-hand polarized wave in the range of electron cyclotron resonance frequency is investigated in the inhomogeneously magnetized and coaxially bounded plasma. The polarization reversal from the left-hand to the right-hand polarized waves near the ECR point is observed. The dispersion relation modified by the boundary condition can explain this polarization reversal, and the observed polarization reversal point is almost consistent with the theoretical one. The unexpected damping of the left-hand polarized wave is found to be caused by the polarization reversal, which inevitably takes place in finite plasmas with boundaries. Our experimental and calculated results are significant for the efficient plasma heating, production, and the control of the local confining potential.

REFERENCE