§58. Steady-State Electron Bernstein Wave Heating and Current Drive Using Phased-array Antenna System

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Electron Bernstein wave heating and current drive (EBWH and EBWCD) is one of attractive candidates of heating and current drive method to sustain the steady-state spherical tokamak (ST) configuration. In the EBWH/CD experiments, some mode conversions from the electron cyclotron (electromagnetic) wave to the electron Bernstein (electrostatic) wave are required. The planned target operation in the first stage of the QUEST is the steady state current drive at ~ 20kA using the O-X-B mode conversion scenario in the rather low-density region. In the O-X mode conversion, the parallel refractive index $N_{//}$ to the magnetic field should be optimized to obtain the high mode conversion efficiency. Figure 1 shows a contour plot of the O-X mode conversion efficiency as a function of toroidal and poloidal refractive indexes exited at the antenna aperture. The central electron density and plasma current were set to 2 x 10^{18} m^{-3} and 20 kA. The O-X-B mode conversion process was analyzed using the TASK-WR ray tracing code for an optimum incident angle [1]. Figure 2 shows the evolution on refractive index $N_{x'}$ in parallel to the density gradient x' direction as a function of $(\omega_{pe}/\omega)^2$. The tunneling during an evanescent layer was required in the non-optimal case at the O-X mode conversion. In order to follow the ray trajectory after the mode conversion, an algorithm to find the ray trajectory point after the tunneling was developed. The tunneling or mode conversion efficiency was evaluated using an analytical formula [2]. The new aspects to analyze the ray trajectory were implemented into the TASK/WR code to treat the non-optimal cases.

In order to excite a pure O-mode in the oblique injection with $N_{//}$, the elliptical polarization should be excited. The incident angle with respect to the magnetic field is a key parameter to excite the optimum $N_{//}$. In order to conduct the EBWH/CD experiments with the O-X-B mode conversion, the advanced antenna system with good directionality and polarization controllability has been required. A Phased-Array Antenna (PAA) system, which enables us to control the launching polarization and angle, was proposed, and the prototype antenna system was designed and has been developed. The basic performances of the prototype antenna to control the incident polarization and angle were confirmed in the low power test facilities. In the prototype antenna, there were significant side-lobe parts. The new CW antenna was designed to reduce the side-lobe parts, and to take the forced water-cooling. The CW antenna performances were also checked at the low power level. Figures 3 show a contour plot of the measured intensity pattern, and the calculated and measured intensity / phase profiles in the steering x direction. The measured profiles were in excellent agreement with the calculated ones. The calculated profiles were evaluated from the developed Kirchhoff integral code. The increased temperature and thermal stress in CW operation were analyzed with finite element codes. The maximum temperature of the CW antenna was 67 degree C, and the thermal stress was evaluated to be moderate.

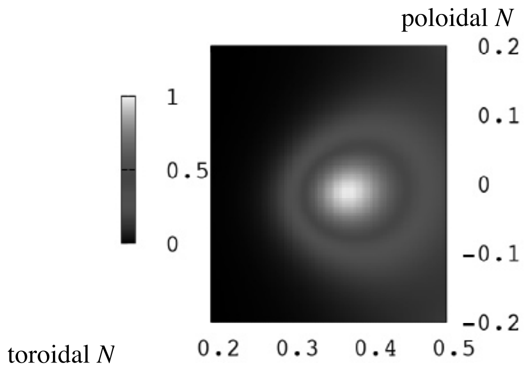

Fig.1 Contour plot of the O-X mode conversion efficiency as a function of toroidal and poloidal refractive indexes exited at the antenna aperture.

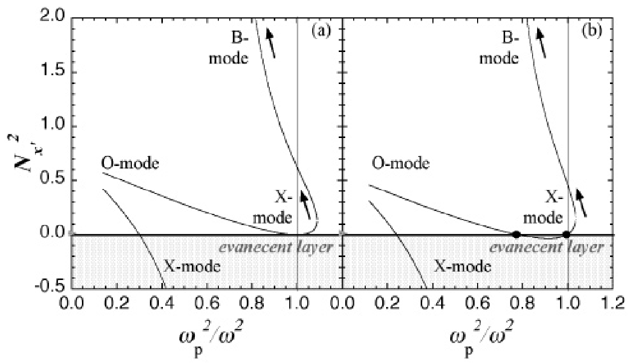

Fig. 2 Evolution on refractive index $N_{x'}$ in parallel to the density gradient x' direction as a function of $(\omega_{pe}/\omega)^2$ in (a): optimum and (b):non-optimal case.

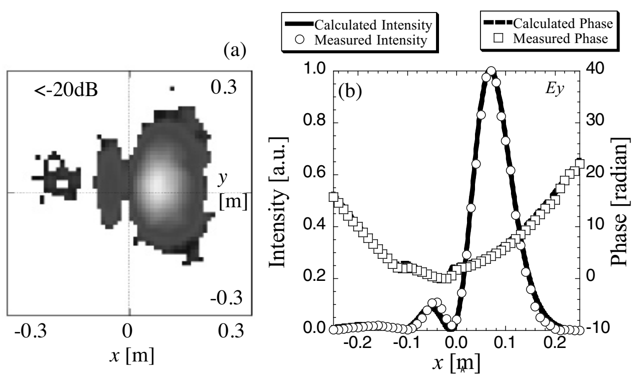

Fig.3 (a): Contour plot of radiated intensity pattern. (b): Calculated and measured intensity and phase profiles in the steering x direction.

[1] H. Idei, *et al.*, J. of Plasma Fusion Res. Series, **8** 1104 (2009).
[2] E. Mjolhus, J. Plasma Phys. **31** 7 (1984).