<Advanced Energy Generation Division> Advanced Plasma Energy Research Section

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Advanced Plasma Energy Research Section

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1. Introduction

The current subjects of this research section are to study the properties of high temperature plasmas in order to control and improve the plasma energy confinement from the physical viewpoint of nuclear fusion research. The experimental and theoretical investigations for the optimization of the helical-axis heliotron configuration are in progress under the collaboration with other groups of the international/national institutes and also groups of other universities under the auspices of the Collaboration Program of the Lab. Complex Energy Processes, IAE and the Collaborative Research Program of NIFS (National Institute for Fusion Science).

In this report, a remarkable result obtained in the Heliotron J experimental study in FY2020 is reported focusing on (1) O-X mode conversion analysis for the electron Bernstein wave heating and diagnostic, (2) development of interferometer system for the electron density measurement and (3) X-ray spectrum measurement in non-resonant microwave heated plasmas.

2. O-X mode conversion analysis using finite element method for EBW heating and diagnostics

Electron cyclotron wave (ECW) is used as one of the methods for heating and diagnostics in magnetic confinement fusion devices. The propagation modes, ordinary (O)-mode and extraordinary (X)-mode, are reflected when the plasma density reaches the cutoff density, resulting that we are not able to access the core region. To solve this problem, O-X-B (from O-mode to X-mode and then electron Bernstein wave (EBW)) mode conversion is proposed. In this study, we have analyzed the optimal conditions for O-X conversion and its conversion efficiency by the finite element method based on the wave equation using COMSOL Multiphysics and compared them with ray-tracing calculations.

We have used a two-dimensional model with a uniform magnetic field and a density gradient in the x-axis direction. we have analyzed the injection condition for maximal O-X conversion efficiency for three parameters, that is, the beam size, the focusing diameter of the injection port, and the angle of incidence, and we have obtained more than 80 % con-version efficiency for the entire injection beam. The conversion from O-mode to X-mode can be seen near the optimum incident angle in Fig. 1(b). In comparison with ray-tracing, there is no significant difference in the optimal angle, and the trajectories of both were consistent as shown in Fig. 1 (d). This suggests that the ray-tracing calculation is useful for finding the optimal incidence angle. In the finite element analysis, the beam width is seen to expand after conversion to X-mode, and the trajectory of the finite width EC beam can be traced.

3. Development of 320 GHz interferometer system in Heliotron J

Measurement of the density profile with high time resolution is required to understand the particle transport in fusion plasma experiments. A new multichannel heterodyne Michelson interferometer with 320 GHz solid-state sources has been designed and is being constructed in Heliotron J for high-density

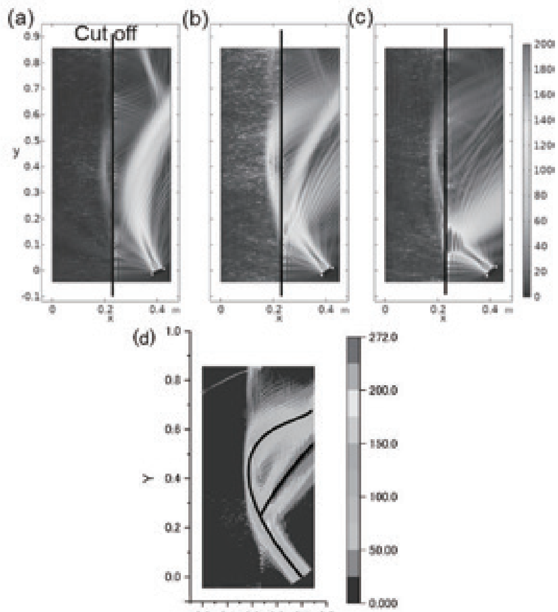

Fig. 1. The electric field norm of O-mode injection (42 GHz). The incidence angle is (a) 25 deg, (b) 35.7 deg and (c) 45deg to the magnetic field (1.8 T), and (d) Trajectory of ECW at optimal incidence conditions. COMSOL (color), ray-tracing (black line).

plasma operation.

To reduce the influence of the plasma refraction effect and ensure that the injected beam returns back in the original direction after reflection, an array of retroreflectors was mounted on the facing wall of the vacuum chamber. To make sure the influence on the beam profile with the retroreflector, an optical test experiment has been done to compare the reflection effects between the metal mirror and the retroreflector.

Figure 2 shows the experimental setup in the optical test experiment. The beam profile was measured by moving a detector in the horizontal and vertical directions. Figure 3 shows the measured beam profiles in the metal mirror and the retroreflector. The beam profile in the retroreflector is more peaked than that in the flat metal mirror, and the signal intensity is high even at large scanning angles, indicating that the retroreflector works for beam transmission. The retroreflector was installed on the inner wall of the vacuum chamber with the angle of less than 40 deg.

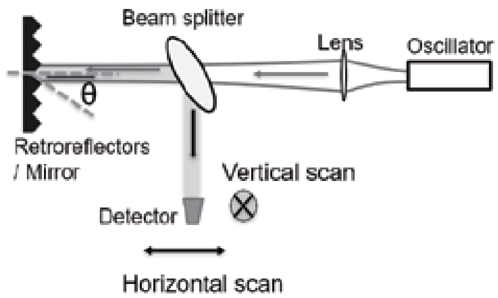

Fig. 2. The schematic view of the test bench experiment for 320 GHz interferometer system

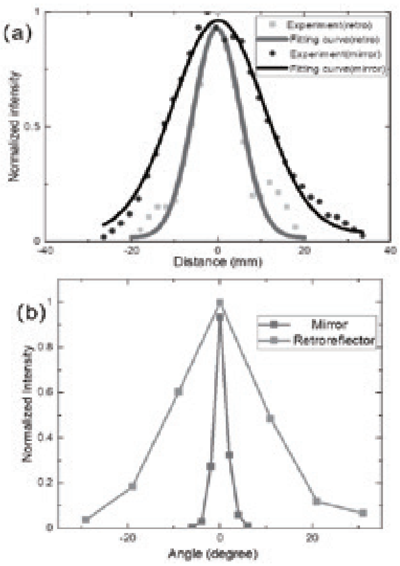

Fig. 3. (a) Beam profile in the horizontal direction and (b) dependence on the scanning angle obtained by the test experiment.

4. Behavior of high-energy electrons in non-resonant microwave heated plasma in Heliotron J

High-energy electrons have been generated by non-resonant 2.45 GHz microwaves in a magnetic field configuration of Heliotron J. To study the production mechanism, we measured the X-ray energy spectrum produced by Bremsstrahlung processes of the high energy electrons. Three sets of $LaBr_3$(Ce) scintillator covered with shields for stray radiation and magnetic field) have been installed to obtain the X-ray spectrum emitted in three (clockwise, perpendicular and counter-clockwise) directions to the magnetic field line. Each scintillator signal is measured with a multi-channel analyzer (MCA) through a pre-amplifier and a shaping amplifier.

Even though the shielding effect by the vacuum vessel was not negligible, we confirmed the existence of MeV-class high energy electrons by the scintillator signal when the detector observes the X-ray flux in the perpendicular direction (see Fig. 4). The peak of the X-ray spectrum around 0.3 MeV may be due to the shielding effect by the Stainless-steel vacuum vessel whose thickness of 20 mm. The strong signal below than 0.1 MeV is attributed to the noise produced by the magnetic coil for the plasma confinement. We also found that the microwave power had a threshold to produce the high energy electrons and that the spectrum weakly depends on the microwave power once the high energy electrons were produced. These results indicate that (1) the observed high energy X-ray flux might be produced by the reactions when the high energy electrons hit the vacuum vessel and (2) the feature is consistent to the production mechanism that the high-energy electrons are produced by the stochastic acceleration.

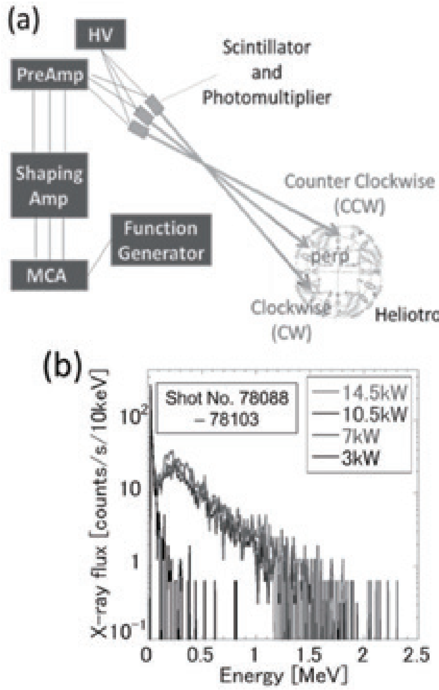

Fig. 4. (a) Schematic view of X-ray measurement system using $LaBr_3$ scintillator and (b) X-ray energy spectrum obtained in non-resonant microwave heated plasmas.

Collaboration Works

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