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Study on Electron Bernstein Emission Diagnostic in Heliotron J
ヘリオトロンJにおける電子バーンスタイン放射計測の検討

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Electron Bernstein Emission (EBE) diagnostic is under development for electron temperature profile measurement in helical-axis heliotron device, Heliotron J. Ray-tracing calculation results using KRAY code show that the X-O mode conversion window is accessible with the existing ECH/ECCD antenna system, and the radiation profile is possible to measure at the core region. A multi-channel radiometer has been assembled and tested.

1. Introduction

Electron Bernstein Waves (EBWs) are electrostatic waves propagating in hot magnetized plasmas at densities not accessible to Electron Cyclotron (EC) waves polarized in the Ordinary (O) or extraordinary (X) mode. This aspect, along with high localization of their emission and absorption, makes EBWs highly attractive for heating, current drive and emission measurements in hot dense fusion plasmas [1]. Being electrostatic waves, EBWs can only exist in a plasma. However, they can be coupled to an external transmitter or receiver by means of mode conversions. Of various schemes proposed, the O-X-B mode conversion and the reverse, B-X-O process, are particularly attractive because they can be geometrically optimized by adopting a special line of sight [2].

An EBE diagnostic is under development for Heliotron J, aiming at measuring core electron temperature in overdense plasmas. In this paper, we show recent progress on the theoretical study and the diagnostic development of EBE measurement in Heliotron J.

2. Ray tracing code for EBE

A ray tracing code, KRAY, has been developed to calculate the ray trajectory and the EBE profile for Heliotron J. The code solves the radiative transfer equations under the geometrical optics approximation [3]. The dispersion relation for the electromagnetic waves is given by a cold plasma approximation. The dispersion relation for electrostatic waves is given by a hot plasma approximation. When the ray reaches the O-mode cut-off layer with optimal angle, it is converted into the X-mode propagating inside the cut-off layer. When the X-mode encounters the upper hybrid resonance, it is mode-converted into the EBW. To calculate the ray trajectory, the three-dimensional magnetic field structure and flux surfaces of Heliotron J is taken into account, which are given by the VMEC code with finite β. Figure 1 illustrates the O-X mode conversion window for 35 GHz frequency waves. Although the toroidal angle in the experiment is up to -15deg due to mechanical limitation of injection angle, it is possible to obtain

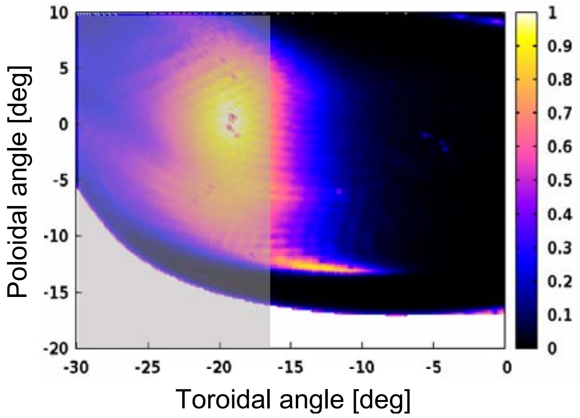

Fig. 1. O-X mode conversion window calculated by KRAY code for 35 GHz frequency at β=1%. The inaccessible area is gray-shaded.

nearly 100% conversion efficiency at the available injection angle. The angle window ranges 5 deg and 2 deg in the toroidal and poloidal angles, respectively. This window region agrees with that estimated by TRAVIS code [4].

The radiation position is located at core region if the magnetic field is properly chosen. As β increases, the magnetic axis is Shafranov-shifted outward, affecting the radiation position. The best frequency to measure the core electron temperature is 35 GHz at 1.25T, where the radiation position closest to the magnetic axis is r/a =0.35.

3. Radiometer system for EBE diagnostic

An EBE radiometer system has been assembled and tested in the laboratory before installation on the Heliotron J device. Figure 2 show a schematic of the radiometer. The radiometer consists of a 24GHz Gunn oscillator, a balanced mixer, a step attenuator, low-noise amplifiers, power dividers, band-pass filters, Shottky-barrier diodes and amplifiers. The band-pass filters of 1 GHz band width allows tuning the 8 channels of the radiometers to frequencies in the 26-41 GHz range. Accessing EBE at these frequencies by means of BXO conversion requires the plasma densities of 0.9-2.1×10^{19} m^{-3} which are routinely obtained at Heliotron J. The radiometer is connected to the transmission line and steerable antenna used for 70 GHz second harmonic X-mode ECH/ECCD system. It will be possible to perform angular scans of conversion efficiency that could provide guidance to EBW heating.

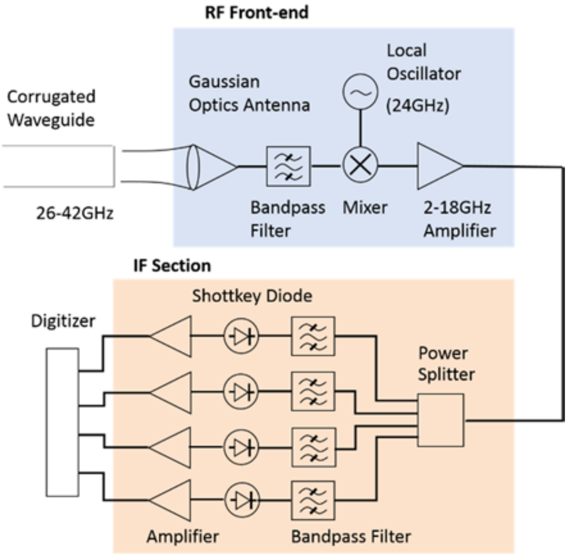

Fig. 2. Schematic of EBE radiometer system.

A waveguide switch has been assembled in the transmission line to switch between ECH/ECCD and EBE. A Gaussian-optics antenna is used to attain high gain, and can simultaneously measure two cross-polarizations. These will be matched to the elliptical polarizations of the oblique O-mode and X-mode by means of a universal polarizer [5], possibly consisting of a λ/4 plate and waveguide rotary joint.

A laboratory test showed that the radiometer can detect 35 GHz microwaves of nW level intensity. Figure 3 shows the output signal intensity of the radiometer. A simulation signal is used to calibrate the output signals. Microwaves of 12-20 GHz with -10 dBm power, generated by a solid-state signal generator, are doubled in frequency to 24-40 GHz with an active multiplier. In this figure, the output signal is normalized by the input signal intensity. It can be seen that the filter system works well to measure the radial T_e profile. The same tendency has been observed at a test using a low-power noise source.

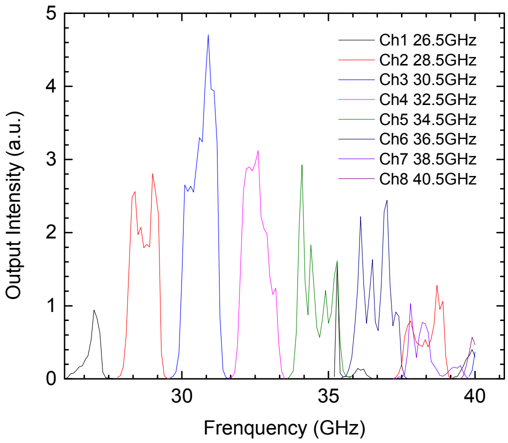

Fig. 3. Laboratory test of EBE radiometer using a microwave source. The input frequency is scanned from 24 to 40GHz.

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[1].H. P. Laqua, et al., Phys. Rev. Lett. **90**, 75003 (2003)
[2].F. Volpe, et al., Rev. Sci. Instrum. **74**, 1409 (2003)
[3].K. Nagasaki, et al, Plasma Phys. Control. Fusion **44**. 409 (2002)
[4].N. B. Marushchenko et al Plasma Fusion Res. **2** S1129 (2007)
[5].F. Volpe, Rev. Sci. Instrum. **81** 10D905 (2010)