21PA-035

# Excitation of Electrostatic Waves in the Electron Cyclotron Frequency Range during Magnetic Reconnection in Laboratory Overdense Plasmas

# オーバーデンスプラズマでの磁気リコネクション中における電子サイクロトロン周波数帯の静電波の発生

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We report the observation of electromagnetic radiation at high harmonics of the electron cyclotron frequency that was considered to be converted from electrostatic waves called electron Bernstein waves (EBWs) during magnetic reconnection in laboratory overdense plasmas. The excitation of EBWs was attributed to the thermalization of electrons accelerated by the reconnection electric field around the X-point. The radiative process discussed here is an acceptable explanation for observed radio waves pulsation associated with major solar flares.

## 1. Introduction

Magnetic reconnection not only converts magnetic energy to kinetic/thermal energy but radiates electromagnetic waves including γ-rays, X-rays, radio waves, and magnetohydrodynamics (MHD) waves and electrostatic waves [1,2].

Fárník *et al.* observed the pulsations of radio waves associated with major solar flares and inferred that the interaction between current loops was the most likely radiation source [3]. Saito and Sakai implemented a two-dimensional simulation of merging of two current loops to understand the above-mentioned phenomenon. They found that the electrostatic waves called electron Bernstein waves (EBWs) excited in the current sheet were converted to the fast extraordinary (X) wave (FXW) through a linear mode conversion process during the merging of current loops [4].

We report an experimental attempt to verify the EBW excitation in the overdense region during magnetic reconnection by merging of torus plasmas (current loops). The verification of the EBW excitation lead to study of the feasibility of the observation of the EBW emission (EBE) as a tool to monitor the electron dynamics in overdense solar/space plasmas.

## 2. Experimental Setup

The experiment was performed in the TS-3 torus plasma merging device at The University of Tokyo [5-7]. The TS-3 device inductively produces two spherical tokamaks (STs) by swinging poloidal field coils. The two STs attract each other and collide via magnetic reconnection. Typical plasma parameters of the TS-3 plasmas are as follows. Major radius: $R_0$ = 200 mm, minor radius: $a$ = 150 mm, toroidal magnetic field and reconnection magnetic field: $B_t \sim B_r = 0.06$ T, electron density: $n_e < 5\times10^{19}$ m$^{-3}$, and the electron temperature: $T_e \sim$ 5-20 eV. During magnetic reconnection, TS-3 plasmas are highly overdense, with $f_{pe} / f_{ce} > 10$, where $f_{pe}$ and $f_{ce}$ are the plasma frequency and the electron cyclotron frequency, respectively.

We employed a radiometer to measure the EBE during magnetic reconnection as shown in Fig. 1.

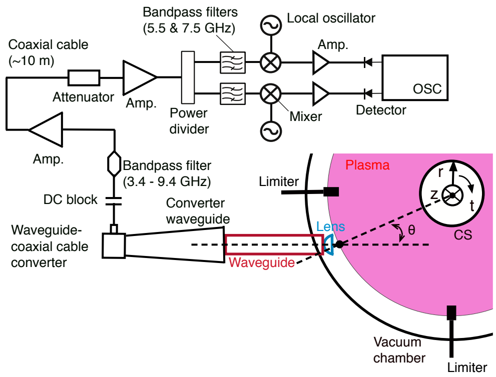


Fig.1. Schematic view of the experimental setup: radiometer with the toroidal cross-section of TS-3.

A cylindrical waveguide antenna connected to a convertor waveguide (circular-rectangular) was installed and was adjustable in a 90-degree range in toroidal direction. The radiometer had two channels with different center frequencies of 5.5 and 7.5 GHz. The bandwidth of the filter was about 0.8 GHz. Frequency range covered by the radiometer corresponds to 2-5 $f_{ce}$ in this experiment.

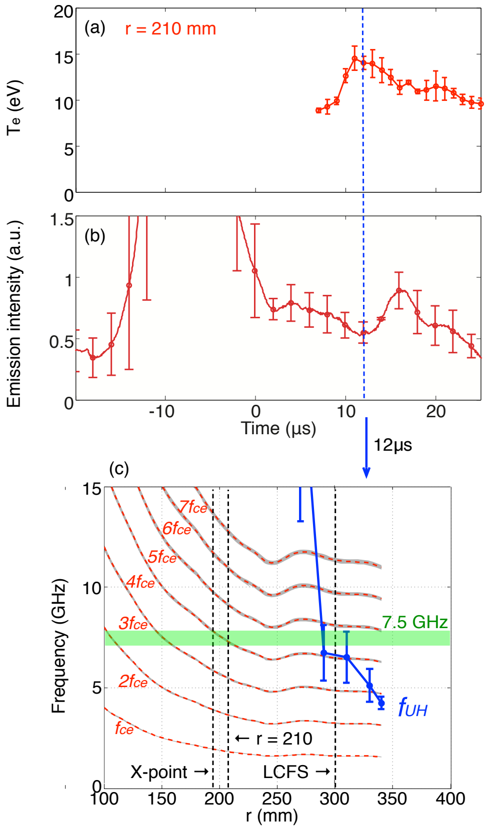


Fig.2. Time evolution of (a) the electron temperature, (b) emission intensity measured by the 7.5 GHz-channel of the radiometer, and (c) the radial profiles of high harmonics $nf_{ce}$ (red lines) and upper hybrid frequency $f_{UH}$ (blue line) at $t$ = 12 μs. The time of onset of magnetic reconnection is defined as $t$ = 0. The EBWs that can be accessible for 7.5 GHz-channel was emitted from $r \sim$ 210 mm (around the X-point).

## 3. Experimental results and Discussion

Figure 2(a)(b) shows the time evolution of the electron temperature and emission intensity. Following the start of magnetic reconnection ($t > 0$), $T_e$ at $r$ = 210 mm in the vicinity of X-point sharply increased to approximately 15 eV. This was due to Ohmic heating accompanied by the generation of the reconnection electric field inside the diffusion region. The emission intensity began to increasing after $T_e$ rise. The time-lag between the peak of the emission intensity and $T_e$ was approximately 5 μs. According to the radial profiles of frequencies as shown in Fig.2(c), the core plasma was opaque to the 7.5 GHz band electromagnetic (EM) waves. Therefore the detected emission during this period is considered to be EBE. The wave packets obtained from the ray-tracing calculation for explanation of the time-lag and the linear mode conversion efficiency [8,9] will be discussed at the poster session.

## 4. Summary

We have reported the observation of enhancement of electromagnetic radiation in the electron cyclotron frequency range during magnetic reconnection in the laboratory overdense plasma. The enhanced EM waves were considered to be converted from the EBWs through linear mode conversion at the upper hybrid resonance. The EBWs were excited by thermalization of electrons accelerated by the reconnection electric field during active reconnection period. We speculate that EBWs are ubiquitously excited in overdense space/solar plasmas, for example, in solar flares. The observation of radio waves converted from EBWs is able to provide information on the thermal motions of electrons in overdense solar/space plasmas.


## Acknowledgments

This work was supported in part by NIFS LHD project collaboration NIFS13KLER018, Grant-in-Aid for Science Research (KAKENHI) 22686085, Grants-in-Aid No. NSC 102-2112-M-006 -013 –MY2 from the National Science Council of Taiwan, and the Top University Project of National Cheng Kung University, Taiwan. The authors wish to acknowledge Prof. Mase (KASTEC, Kyushu University) and the members of the plasma heating physics research division of National Institute for Fusion Sciences (NIFS) for helpful comments on this research.


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