2D measurement of field-aligned intermittent high-energy electron flux in an ECR discharge plasma

S. Yoshimura[1], K. Terasaka[2], Y. Kato[2], M. Aramaki[3], and M.Y. Tanaka[2]
[1]*National Institute for Fusion Science, Toki, Japan*
[2]*Interdisciplinary Grad. Sch. Eng. Sci., Kyushu University, Kasuga, Japan*
[3]*Dept. Elec. Eng. Comp. Sci., Nagoya University, Nagoya, Japan*

1. Introduction

Intermittent phenomena are ubiquitous in laboratory, space and astrophysical plasmas. Bursty transport of energy and particles observed in many magnetically confined plasmas and explosive energy release of the sun in the form of solar flare are typical examples.

Recently, we have observed spontaneous emission of field-aligned intermittent high-energy electron fluxes in a cylindrical electron cyclotron resonance (ECR) plasma [1]. The emergence and dissipation of pulsed electron fluxes are found on the whole plasma cross-section, and the typical duration time is 10 μs for a helium plasma. Our previous experiment using two Langmuir probes implied that the electron flux has a finite spatial size perpendicular to the external magnetic field. Because of the intrinsic intermittency of the phenomenon, it is difficult to determine the size and the occurrence position of the electron flux with a few probes; we have therefore developed a wire-grid probe which is capable of reconstructing 2D distribution of the high-energy electron flux with a simple procedure.

2. The wire-grid probe

In order to investigate the spatial distribution and the point of occurrence of the electron flux, we have developed a wire-grid probe which consists of 16 electrodes (8 horizontal and 8 vertical) as shown in Fig.1. Each tungsten-wire electrode is electrically independent and connected to a high impedance resistor for measuring the floating potential, because the floating potential is very sensitive to the existence of high-energy electrons and shows negative spiky variation corresponding to the influx of such electrons. Another advantage of measuring floating potential is smaller disturbance to the plasma compared with that of a biased probe. Standard voltage-follower circuit with a precision high-speed operational amplifier (Burr Brown, OPA627AP) ensures high frequency (< 200 kHz) response of the output signal of each channel.

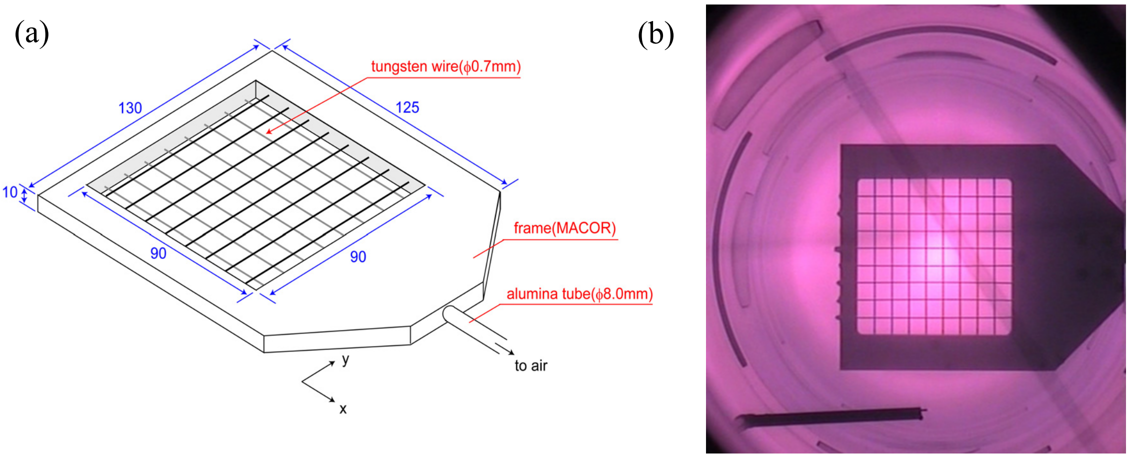

Figure 1: (a) Schematic of the wire-grid probe. (b) A CCD image taken through the view port window at the end flange of the HYPER-I device.

Taking the geometric means of all pairs of horizontal and vertical signals, we can reconstruct the 2D intensity map of electron flux with 64 lattice points from only 16-channel measurement. The intensity of the lattice point (i, j), $F_{i,j}$, is given by

$$F_{i,j} = \sqrt{\tilde{V}_{\mathrm{f},i} \times \tilde{V}_{\mathrm{f},j}}\ , \quad (1)$$

where $\tilde{V}_{\mathrm{f}}$ denotes the perturbed quantity of floating potential, and the subscripts i (=1-8) and j (=1-8) represent the horizontal and vertical wires, respectively. In a Maxwellian plasma with one-temperature electrons, floating potential is a linear function of the electron temperature. However, under the existence of small amount of high-energy electrons, the floating potential no longer holds such simple relation [2]. Likewise, the quantity $F_{i,j}$ is not a linear function of high-energy electron flux but has a positive correlation to the change in total electron flux. The quantity $F_{\mathrm{i,j}}$ becomes large only when the electron flux simultaneously hits the i-th horizontal wire and j-th vertical wire. Therefore, we tentatively evaluated the intensity of high-energy electron flux at each lattice point using eq. (1) in this study.

3. Experimental setup

The experiment was performed in the HYPER-I device [3] at the National Institute for Fusion Science. HYPER-I is a cylindrical device with 0.3 m in inner diameter and 2.0 m in axial length. A helium plasma was produced by ECR heating with a 2.45 GHz microwave. The input microwave power and the neutral gas pressure were fixed at 20 kW and 1.5 mTorr, respectively, and the typical electron density and the balk electron temperature were 10^{17} m^{-3} and 10 eV, respectively. The wire-grid probe was installed at the center of the plasma cross-section, 1.175 m apart from the microwave injection window.

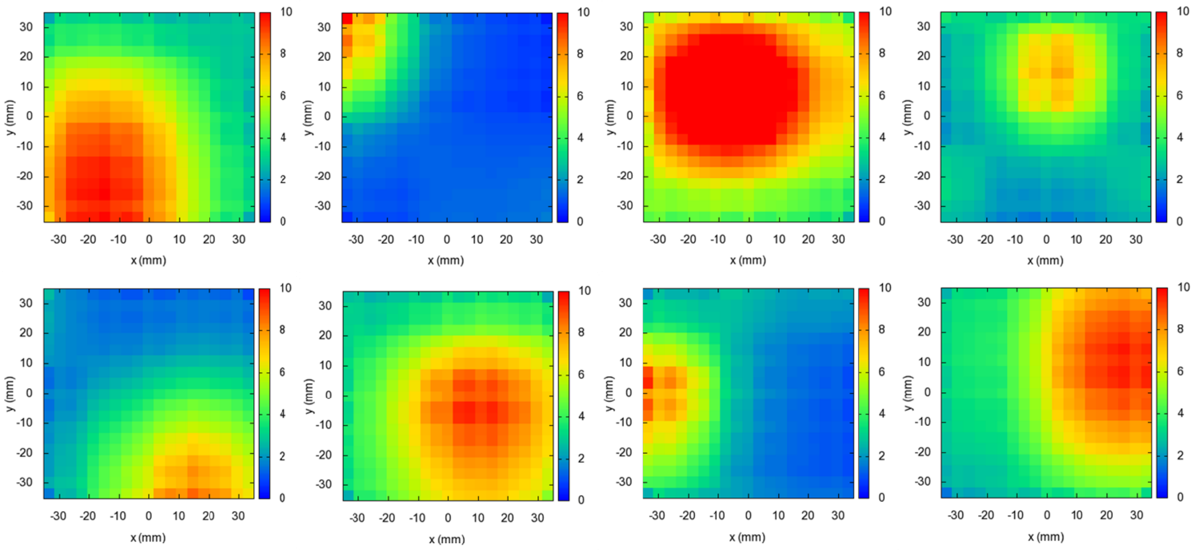

Figure 2: Reconstructed 2D distributions of the intermittent electron fluxes using the wire-grid probe.

4. Experimental results

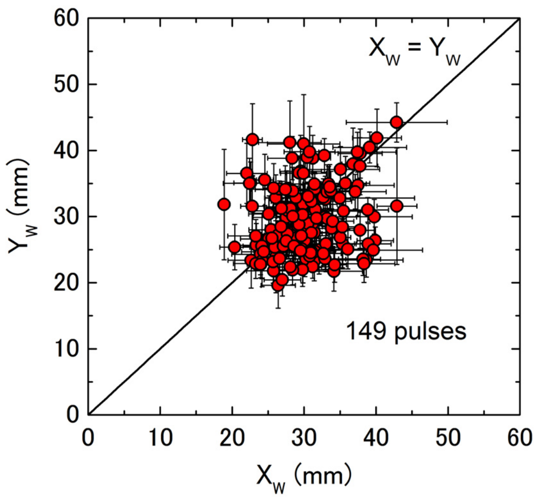

Figure 3: The size distribution of the electron fluxes determined by 149 pulses that are picked up as samples.

Figure 2 shows the 2D distributions (intensity maps) of the intermittent high-energy electron fluxes, where the origin (x, y) = (0, 0) corresponds to the cross-sectional center of the device. It is found that the reconstructed electron flux has a finite spatial extent with a circular cross-section. It is also found that the point of occurrence seems to be random in the measurement area of the wire-grid probe, and the fluxes have various intensities.

Figure 3 shows the size distribution of the intermittent high-energy electron fluxes evaluated from 149 samples with various peak intensities, where the quantities X_w and Y_w represent the full width at half maximum (FWHM) of the $F_{i,j}$ in x and y directions. It is clear that most of the data lie on the solid line $X_w = Y_w$ indicating the spatial profile of the electron flux on the plasma cross-section is circular, which justifies the impression given by Fig. 2. In addition, the diameter is limited within a range of 30 ± 10 mm in spite of the variety of peak intensities. 2D measurement using the wire-grid probe makes it possible to obtain the spatial information which was not available with a few single probes.

5. Statistical property

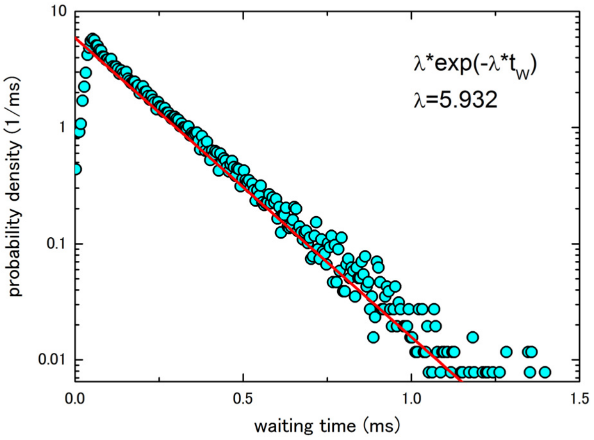

Figure 4: Semi-logarithmic plot of the probability density of waiting time.

The wire-grid probe can provide not only spatial but temporal information from the time-series of floating potential variation. For example, the statistics of waiting-time contains important information on the mean rate of occurrence and the randomness of the events. Here the definition of the waiting-time is the time interval between two minima of consecutive negative spikes. Figure 4 shows the probability density of waiting-time in a semi-logarithmic scale. The solid line in Fig. 4 shows an exponential distribution, which implies that the intermittent high-energy electron emission event can be considered as a stationary Poisson process, i.e. a sequence of events which occur randomly and independently of one another. The results of detailed statistical analysis including the duration time statistics will be published elsewhere.

6. Conclusion

We have developed a wire-grid probe which is capable of obtaining spatial information on the intermittent high-energy electron flux in an ECR plasma. The electron flux intensities in 64 lattice points can be evaluated by floating potential variation of 16 electrodes. It is found that the electron flux has a circular cross-section with a diameter of 30 ± 10 mm. The waiting-time statistics exhibits the exponential distribution, which implies the random nature of the intermittent electron flux emission event in this study.

Acknowledgment

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