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Development of a High Speed VUV Camera System for 2-Dimensional Imaging of Turbulent Structure in LHD

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In fusion plasmas, a turbulent transport effects greatly on a plasma confinement. In order to clarify the role of the turbulent transport, measurements of fluctuations with high time and spatial resolutions are necessary. In this case, if 2-dimensional structures are observed, the more detailed characteristics of turbulence can be clarified, since a propagation direction of the fluctuations and the mode number are found in visually. Therefore, a high speed vacuum ultraviolet (VUV) camera system for 2-dimensional imaging of turbulent structures was developed and installed in LHD. This optical system is composed of 2 multi-layer mirrors made of Mo / Si and a micro-channel plate (MCP). An emission from plasma reflects at the multi-layer mirrors with high reflectivity and images on the MCP. The VUV emission near 13.5 nm of impurity carbon (n = 4-2 line of C VI) can be observed. In analysis of the camera image, an inverse transformation of the line-integrate data is required for the deviation of the turbulent structure. In this paper, the constitution of this VUV camera system and an analytical method are described in detail, and moreover preliminary results observed in LHD are shown.

Keywords: 2-dimensional imaging, vacuum ultra-violet, impurity carbon, turbulent structure

1. Inroduction

In fusion plasmas, a turbulent transport effects greatly on a plasma confinement. For edge transport barrier plasmas, the turbulence suppressions by sheared E x B flow have been observed [1]. Recently, oscillating E x B flows called zonal flows have emerged as an important part of the overall turbulence physics [2].

The measurement of turbulence needs both high temporal and high spatial resolutions. We want to know a 2-dimensional turbulent structure to clarify a propagation direction of fluctuations, the mode number and so on. In a large helical device (LHD), an edge transport barrier plasma and an internal diffusion barrier plasma are observed and researched in recently. The clarification of the turbulent structure in the plasmas is important to clarify physical mechanisms of these transport barriers.

Therefore, we developed a new 2-dimensional imaging diagnostics for turbulent structures, which called “a high speed vacuum ultraviolet (VUV) camera system”. This VUV emission from impurity carbon reflects an impurity fluctuation, and a fluctuation of an electron density can be estimated as a result. This system has an advantage that a light intensity is larger than that of a pinhole type optical system. This high speed VUV camera system was installed on LHD and preliminary data were obtained.

2. High speed VUV camera system

A high speed VUV camera system is constituted by multi-layer mirrors, an MCP and a high speed camera as shown in Fig.1. VUV light can only travel in a vacuum region, therefore the system is composed in vacuum chamber except the high speed camera.

The multi-layer mirror is made of Mo / Si (typical thickness is 6.66 nm, dMo : dSi = 4 : 6) and the reflectivity is about 50-60 % [3]. This mirror is mainly reflect the VUV light of 13.5 nm (half band width is about 1-2 nm). This wavelength is corresponds to the impurity carbon line (n = 4-2 line of C VI) [4]. There are two multi-layer mirrors in the system. One of these mirrors reflects the VUV light from plasma by the convex mirror (curvature radius is 144.5 mm), the other reflects the light and images on the MCP by the concave mirror (curvature radius is 390 mm).

The MCP (Tokyo instruments, inc.) is an electron-multiplier device which multiply electrons detected 2 dimensionally. Since the MCP has sensitivity for not only electron but also ion, VUV light and X-ray, the MCP is also used for those detected devices. The MCP has the phosphor screen of 48 mm in diameter in order to image the output signal optically. In experiment, the MCP is biased high voltage to observe the VUV light. The MCP has two layers and one layer is the output of rhe assembly (Vo), the other is the input of the assembly (Vi). The phosphor screen is applied upto +3.0 kV, Vo is connected to ground and Vi is applied upto -1.5 kV. The output intensity can be controlled by changing the value of the high voltage.

The 2-dimensional image of the phosphor screen of MCP is recorded by a high speed camera. We used the

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Phantom v4.2 camera of the Vision Research, Inc. This camera can record up to 15300 pictures per second (pps) in 256 × 128 pixels. The obtained data is transferred to the PC through an optical fiber and stored in there.

The overall view of the high speed VUV camera system together with LHD vacuum vessel and plasma is shown in Fig.2 and the top view of that is shown in Fig.3. The focal length of the multi-layer mirrors is about 7 m, thus the mirror is placed from the plasma center by the length. The plasma image is reduced by 1 / 60 by mirror optic and focused on the MCP screen. Since the diameter of the port, we are using now, is smaller than initial design, only the 1 / 3 of the image (5.5 mm at the entrance of the MCP) can be measured now.

3. Analytical method

The obtained 2-dimensional data do not directly reflect the plasma fluctuations because of the line integrated effect. Particularly, the situation in the helical plasma is more complicated than that in the tokamak plasma. The obtained data need to be reconstructed in order to know the actual 2-dimensional fluctuation data.

In order to analyze the turbulent structure, it is supposed that a radiation along magnetic field lines is constant. We need to know the equivalent field lines of sight in the region of the view line [5]. The Fourier – Bessel expansion method [6, 7] will be used in the reconstruction of the radiation intensity.

Moreover, the simulation of the profiles of the emission of impurity carbons is needed to predict the experimental emission profile. The IONEQ code [8] for LHD developed by Dr. A. Weller will be used to simulate the emission.

4. Experimental results

Preliminary data was obtained by using the high speed VUV camera system in LHD. The following data was measured by camera speed of 2000 pps and 256 × 128 pixels.

Figure 4 shows the time evolutions of neutral beam injection (NBI), plasma stored energy (W_p), line integrated density (nL), power of radiation (P_{rad}), H_α emission, C III emission and measured VUV emission at the position of (x, y) = (119, 65) pixel where is the center of the MCP. This plasma was heated by four NBIs and hydrogen pellets were injected for t = 2.6-2.9 s. A time evolution of the emission at (x, y) = (119, 65) is similar to C III emission, P_{rad} and H_α emission. A rapid small increase at t = 3.465 s in VUV emission is also observed for C III emission, however, not observed for P_{rad} and H_α emission. Therefore, the observed emission may reflect carbon impurity emission of 13.5 nm. Since there is a possibility that the observed emission includes the low-energy light which wave length is not 13.5 nm, we will improve the high speed VUV camera system by using a low-energy-cut filter.

The 2-dimensional image at t = 2.8205 s is also shown in Fig.4. The emission inside of the imaging area (< 5.5 mm in diameter) was observed. The emission outside the imaging area may be a stray light. The analysis of this 2-dimensional VUV emission is now proceeding.

5. Summary

A high speed VUV camera system was developed and preliminary data was obtained. The 2-dimissional VUV emission was successfully observed. It is necessary to improve this system to observe the VUV light of higher strength for measurement of the turbulent structure at a high resolution time. This new diagnostics have a possibility to become a useful and powerful tool for 2-dimensional imaging of turbulent structures in fusion plasma.

Acknowledgments

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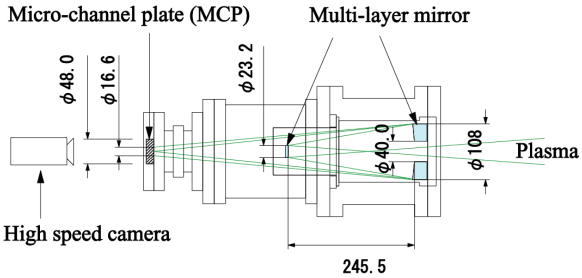

Fig.1 High speed VUV camera system.

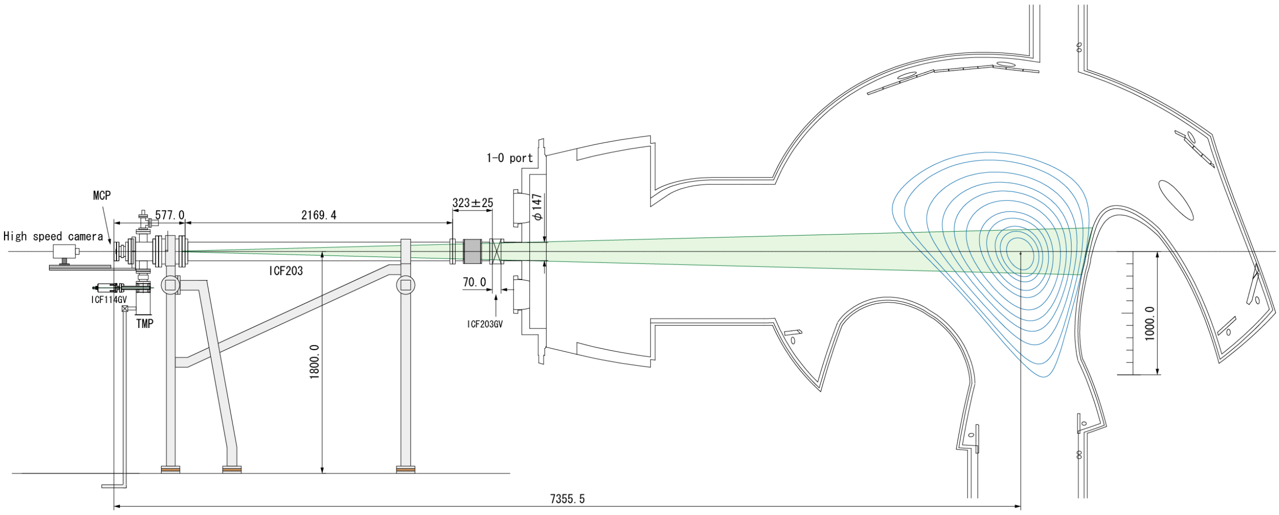

Fig. 2 The overall view of the high speed VUV camera system together with LHD vacuum vessel and plasma.

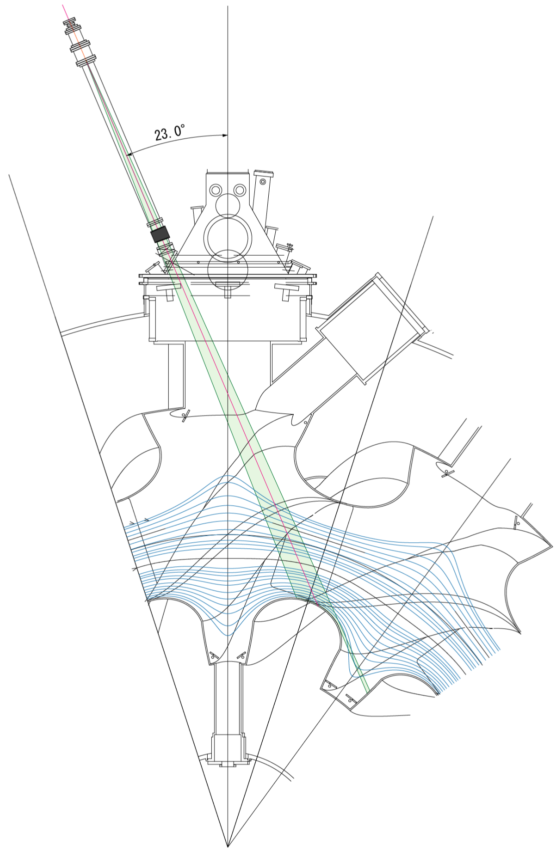

Fig.3 The top view of the high speed VUV camera system together with LHD vacuum vessel and plasma.

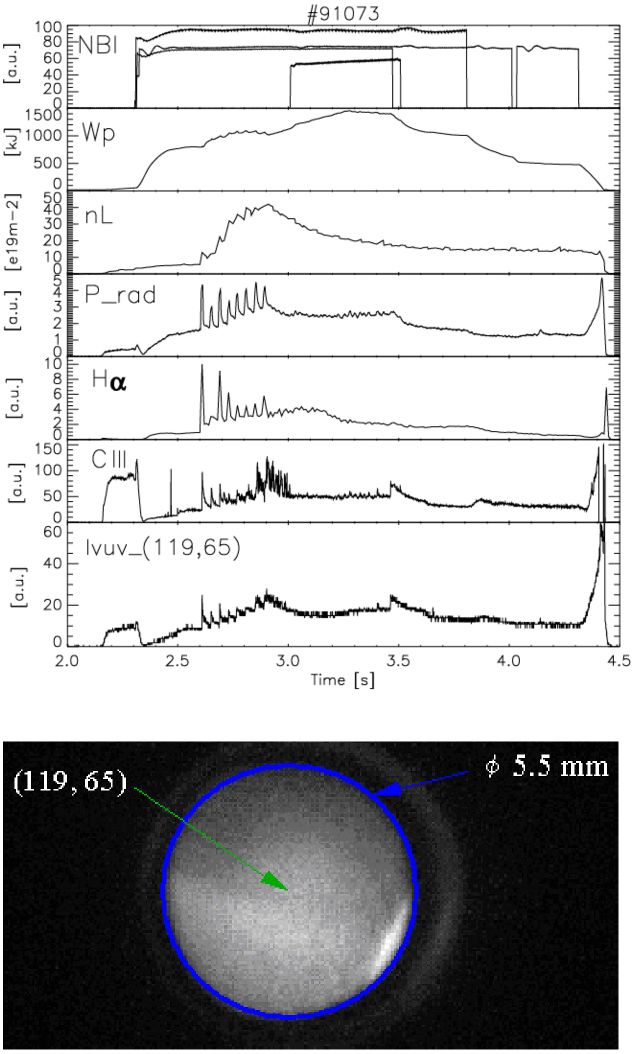

Fig.4 Time evolutions of NBI, Wp, nL, Prad, H_α, C III and VUV emission at (x, y) = (119, 65) pixel where is the center of the MCP and an image of camera at t = 2.8205 s in #91073. The imaging region is inside the circle of 5.5 mm in diameter.