Measurement of blob-like structure behavior in the plasma edge in QUEST

H.Q. LIU¹, K. HANADA², N. NISHINO³, R. OGATA¹, M. ISHIGURO¹, H. ZUSHI², K. NAKAMURA², K. N. SATO², M. SAKAMOTO², H. IDEI², M. HASEGAWA², Y. HIGASHIZONO², S. KAWASAKI², H. NAKASHIMA², A. HIGASHIJIMA², and QUEST GROUP

¹ IGSES, Kyushu University, Kasuga, Fukuoka, 816-8580, Japan
² RIAM, Kyushu University, Kasuga, Fukuoka, 816-8580, Japan
³ Department of Mechanical System Engineering, Graduate School of Engineering, Hiroshima University, Japan

Measurement of blob-like structure in the boundary region of ECRH plasmas in a simple magnetic configuration in QUEST (major radius, R = 0.68 m, minor radius, a = 0.40 m and toroidal magnetic field, Bt = 0.25 T at R = 0.64 m) using combination of a fast imaging camera with a movable and rotatable Langmuir probe system was presented. The blob-like structures, which had an elongated structure along the magnetic field line and moved in the radial direction, were observed. The observed 2-D evolution of these structures strongly depended on the value of Bz/Bt, where Bz shows vertical magnetic field. Ion saturation current was asymmetric in terms of time when the blob-like structure was passing. This means that plasma in the blob-like structure hunches over, which is the same of blobs in other devices [G. Y. Antar et al., Phys. Rev. Lett. 87, 065001 (2001)]. The typical radial velocity of the blob-like structure is ~ 1 km/s. Average amplitude of electron density and electron temperature of the blob-like structures are as large as 4 times and 1.6 times those of the background plasma value, respectively.

Keywords: blob-like structure, edge plasma, QUEST, fast camera, Langmuir probe

1. Introduction

Recently experimental and theoretical work suggested that in the plasma boundary region fluctuation-driven transport across the magnetic field lines is largely dominated by the radial motion of magnetic-field-aligned filaments or meso-scale coherent structures, as named blob. These structures contain excess density and temperature as compared with the background plasma and possibly lead to serious erosion of the wall, impurity production, heat and particle load, and particle recycling that may become critical for ITER [1-3]. The study of plasma blobs and the resultant intermittent convective transport is one of the most active research areas in plasma physics because they seem to be a universal phenomenon found irrespective of the details of the magnetic geometries, devices, parameters, as well as the underlying instability driving forces or dissipation processes [4]. While substantial progress has been made in understanding blobs, the mechanism of blob formation still remains as an open question. Recent experimental results from a simple magnetized torus shed some light on the mechanism of blob formation [5]. Some two-dimensional fluctuation measurements, such as those from fast cameras, beam emission spectroscopy (BES) and probe array measurements in several devices have been used to investigate blob structures in the plasma boundary region [6-8]. In the Q-shu Univ. Exp. with Steady-State Spherical Tokamak (QUEST), the blob-like structures with intermittent and frequent bursts was observed simultaneously with combining Langmuir probe and a fast camera in the edge plasma in a fundamental plasma magnetic configuration characterized by a slab plasma and open field lines. The features and the radial motion of the observed blob-like structures are presented.

2. Experimental set-up

QUEST is a medium sized spherical tokamak, which has advantage of improved high beta stability compared to conventional tokamaks and charged with a mission to study issues related to steady-state operation. And it has a major radius of R = 0.68 m, minor radius of a = 0.40 m, diameters of the center stack and the outer wall of ~ 0.2 m and ~ 1.4 m, respectively and flat divertor plates at the vertical distance from the midplane, Z = ± 1 m. In this experiment, hydrogen plasma were initiated by using electron cyclotron resonance heating (ECRH) at 2.45 GHz in the magnetic configuration with the vertical and the toroidal magnetic field, Bz and Bt.

To visualize the motion and study the characteristics of blob-like structures, a combination of a fast camera and a movable and rotatable Langmuir probe were used, as shown in Fig. 1. The Langmuir probe has five tungsten pins, whose diameter and length are 1 mm³ × 1 mm.©2010 by The Japan Society of Plasma Science and Nuclear Fusion Research
separated by ~7 mm in toroidal and poloidal directions and A, B, C and D, E pins radially separated by ~5 mm as shown in Fig. 2. Two methods are applied to measure. The first method, as shown in Fig. 2 (a), allows the simultaneous measurement of the floating potential (A, D and E), positive bias (B) and ion saturation current (C) in two orthogonal directions (toroidal and poloidal directions) in the outboard mid-plane region. The second method use A, B and C to measure the floating potential in poloidal direction, and thus fluctuations of the poloidal electric field can be deduced from the difference in the floating potential signals $V_f$, as shown in Fig. 2 (b). The probe signals were sampled at 1 MHz. The distance between the probe head and the first wall is about 25 cm.

3. Experimental results

3.1 Visualization of blob-like structures

Fig. 3 shows a typical two dimensional imaging with 10000 FPS in ECRH discharges with different $B_z/B_t$. It is clearly that the blob-like structures move across the magnetic field and form an elongated structure along the magnetic field line. $B_z$ plays an important role as an experimental control parameter via its action on the magnetic topology, defining the distance $\Delta = 2\pi R (B_z/B_t)$ between two point in the poloidal plane connected by the same field line, and the connection length $L = 2a (B_z/B_t) = 2\pi R (2a)/\Delta$. With different the ratio of $B_z/B_t$, the helix angle and vertical wavelength $\lambda_z$ of initial helix-sinusoidal perturbations are different [9, 10]. It suggested the blob-like structure size in the plasma edge strongly dependent on $B_z$ and thus the connection length. Small blob-like structures have high frequency and
large-scale ones have low frequency existing in the boundary region. The large scale blob-like structures are more important because they have long lifetime and can move a long distance before its disappearance, some largest blob-like structures can even pass through the boundary region and directly interact with the surface of the first wall. The existence of these blob-like structures considerably enhances the direct interaction of plasma with the wall materials.

3.2 Isolated blob-like structures

The raw signals of ion saturation current, $I_s$, is proportional to $nT_e^2$, shown in Fig. 4 (top) for a time interval of 20 ms at the 25 cm inside from the wall in the outboard mid-plane region. There is an abundance of intermittent large amplitude bursts in time series which appear to have an asymmetric waveform. These bursts are identified with blob-like structures since their isolated structure is similar with blob in the major characteristics [11], namely the pulse amplitude is higher than the root-mean-square (rms) fluctuation level, the pulse duration is longer than $\delta_{mn}/|V_r|$, where $\delta_{mn}$ is the minimum detectable blob size $\sim 7 \text{ mm}$, and the burst exhibits a steep front (sharply rising front) and trailing wake (slowly decaying tail). The asymmetric burst shape is supposed to be induced by the radial motion of blob-like structure. One burst taken at random was enlarged and showed the typical isolated blob-like structure in Fig. 4 (top). For considering a typical duration of blob-like structures in $I_s$ signal, the conditional average method [12] was used to analyze the bursts signal. The $I_s$ signal was used as reference signal, when $I_s$ exceeds a certain threshold $k$, an organized event a time scale $t_a$ is considered to occur. The certain threshold is of $I_s=1.2\text{mA}$, the time scale is of $t_a=120\mu\text{s}$ in Fig. 4 (bottom); Because blob-like structures have an asymmetric waveform, the conditional average was calculated with a time scale from $-t_a/3$ to $2t_a/3$. The conditional average of these events also clearly shows the asymmetric waveform of blob-like structures. The HWFM of the typical duration of one burst event is about 15 $\mu\text{s}$. The average amplitude of $I_s$ is about 2.5 mA, much higher than the background plasma value, 0.15mA, and the rms value, 0.2mA. The Fig. 4 (bottom) also clearly shows that the blob-like structures have similar asymmetric waveform even if the $B_z/B_t$ is different in four discharges, 3785# ~3788#.

Two dimensional numerical simulations of the dynamical evolution of a blob-like structure initially at rest in an homogeneous plasma have demonstrated fast radial acceleration, formation of an asymmetric waveform, and radial motion over a distance many times the initial structure size [11, 13, 14]. The formation of an asymmetric waveform was already demonstrated by probe signal above in our experiment. The radial acceleration and the radial motion over a distance many times the initial structure size were also demonstrated by fast camera imaging in the
plasma edge in Fig. 5 in this experiment.

### 3.3 Motion and Features of the blob-like structure

One-dimensional analysis on the image are tried to study the motion and features of the blob-like structure. Fig. 5 (a) shows time evolution of the light intensity of each pixel on the line in the mid-plane. It clearly showed that the radial motion of blob-like structure over a distance many times the initial structure size. The lifetime of the blob-like structures is roughly from 300 $\mu$s to 700 $\mu$s and the frequency of the intermittent blob-like structures is from 0.7 kHz to 4 kHz, average value is about 1.4 kHz, respectively. And also the radial velocities of blob-like structures are estimated from Fig. 5 (b, c) of 0.9 km/s and 1.8 km/s in radial direction. Comparing Fig. 5 (b) with Fig. 5 (c), the blob-like structure should be noted that acceleration along the path. The average radial velocity of blob-like structure is about 1 km/s in near the probe area. In the plasma source region, the radial velocity of blob-like structures is of $V_b < 1$ km/s and in the vacuum region is of $V_b > 1$ km/s.

The fluctuation value in blob-like structure was derived from the probe signals. The electron density ($n_e$) and the electron temperature ($T_e$) of back ground plasma are $6 \times 10^{16}$ m$^{-3}$ and 4.5 eV. Using the ion saturation current as referential signal, the conditional averaging of $n_e$ and $T_e$ were obtained and shown in Fig. 6. Average amplitude of electron density is as large as 4 times the background plasma value. Average amplitude of electron temperature is 1.6 times higher than the background plasma value. It suggests that the blob-like structures are at least high electron density region and the hot electron region and are believed to enhance the direct interaction of plasma with the wall materials.

### 4. Conclusions

A combination of fast camera and a movable Langmuir probe was powerful tool to study the edge plasma phenomena. The blob-like structures was observed, which is along the magnetic field and moves across the magnetic field. The camera images with 40000 FPS and the ion saturation current by Langmuir probe revealed that each turbulent burst had a similar asymmetric wave form which typical duration is about of 60 $\mu$s. The radial motion and features of the blob-like structure were estimated from the one dimensional analysis on the image. And the electron temperature and electron density derived from the probe signals suggested there is excess particle and heat in the blob-like structure region.

The blob-like structures size in the plasma edge strongly depends on the connection length. Large scale blob-like structures are intermittently detected at the plasma edge region. They are moving outward. The large scale blob-like structures can even pass through the boundary region and directly interact with the surface of the first wall because their long lifetime, despite their small population and low occurrence frequency.

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