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

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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 toridal magnetic field, B_t = 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 B_z/B_t, where B_z 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 ~ 1km/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, B_z and B_t.

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 mm^Ø × 1 mm^L,

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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.

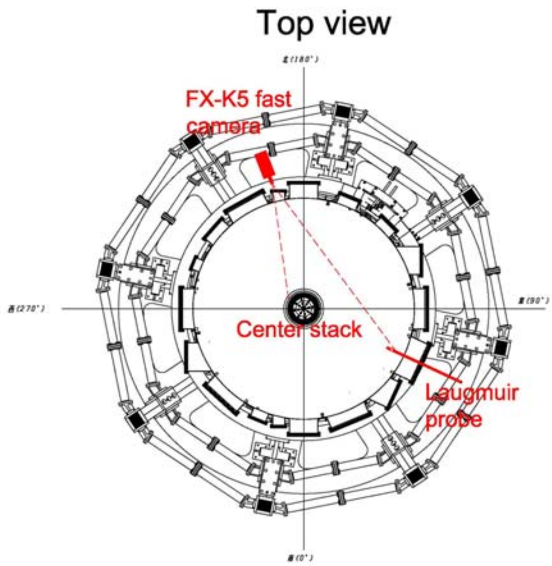

Fig. 1 A schematic of combination of Langmuir probe and fast camera.

The framing rate of camera was typically set at 40000 FPS (frames per second) with 192 × 144 pixels each frame, 20000 FPS with 288 × 240 pixels each frame and 10000 FPS with 320 × 240 pixels each frame in different discharge conditions. For observing the blob like structure with the probe, the maximum framing rate of the fast camera was set at 40000 FPS with 192 × 144 pixels each frame was used and its viewing area was half plasma space which probe head located in. Although no filter was used to measure, the observed visible image was mainly attributed to the H_α emission ($\propto n_0 n_e$) [8].

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

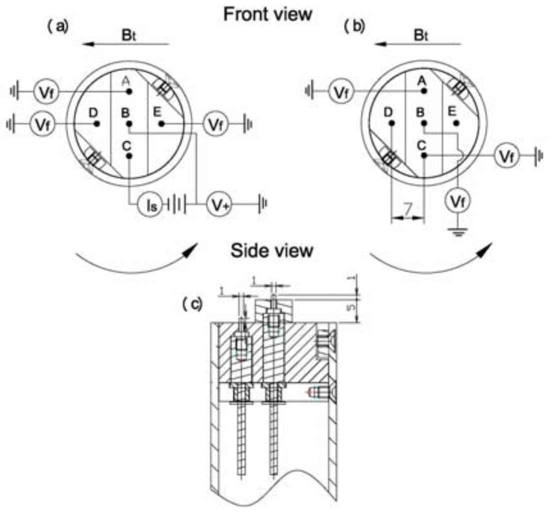

Fig. 2 Schematic view of the Langmuir probe array in the QUEST tokamak. Two orthogonal directions can be measured. One was shown in this scheme, another one was that the probe head rotates 90° along the curve arrow.

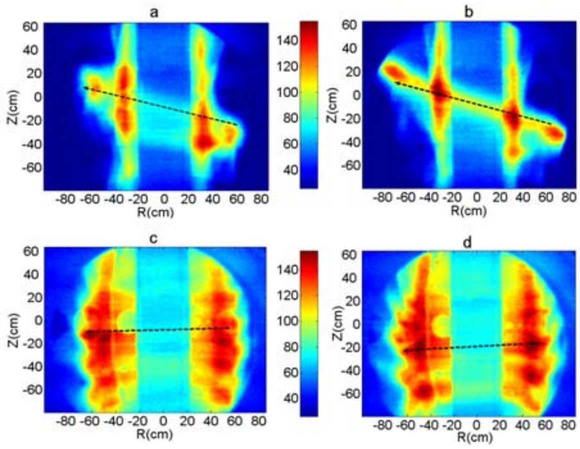

Fig. 3 The dimensional imaging for two cases of B_t = 365 G, B_z ~ 100 G (a: 0.6596 s, b: 0.6597 s) and B_t = 500 G, B_z ~ - 28 G (c: 0.4750 s, d: 0.4751 s) with 10000 FPS in ECRH plasma in QUEST. The dot line arrow indicated the direction of B.

magnetic field line. B_z plays an important role as an experimental control parameter via its action on the magnetic topology, defining the distance $\Delta \equiv 2\pi R(B_z/B_t)$ between two point in the poloidal plane connected by the same field line, and the connection length $L \equiv 2a(B_t/B_z)=2\pi R(2a)/\Delta$. With different the ratio of B_z/B_t, the helix angle and vertical wavelength λ_z of initial helix-sinusoidal perturbations are different [9, 10]. It suggested the blob-like structure size in the plasma edge strongly dependents 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 $nT_e^{0.5}$, 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 $\delta_{min}/|V_\theta|$, where δ_{min} is the minimum detectable blob size ~ 7 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 =1.2mA, the time scale is of t_a = 120μs 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 μs. 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#.

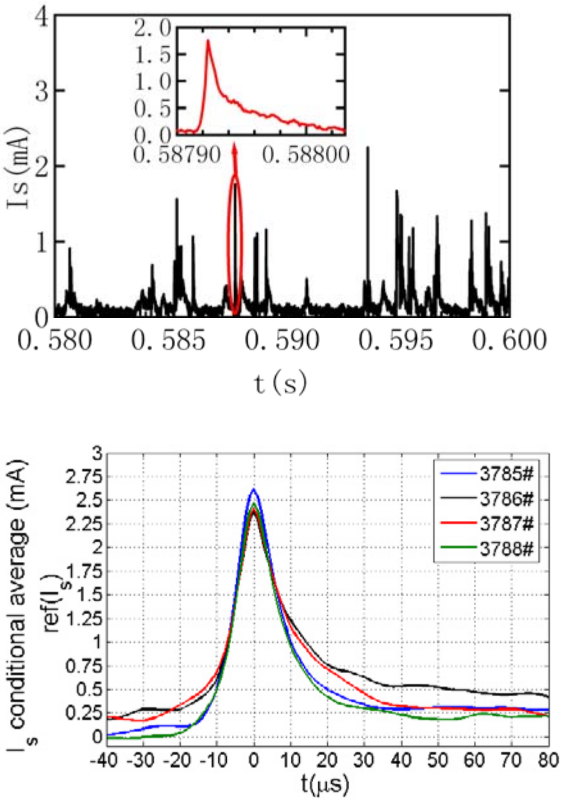

Fig. 4 (top) Raw signals of ion saturation current I_s, a time interval of 20ms, Shot No.: 3786#. The inset is that one burst taken at random was enlarged and showed an isolated blob-like structure with asymmetric waveform; and (bottom) I_s conditional average (Ref: I_s > 1.2mA, t_a = 120μs) of four shots in different condition (3786#, 3787#: B_z/B_t ~ 0.25, 3785#, 3788#: B_z/B_t ~ 0.13).

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

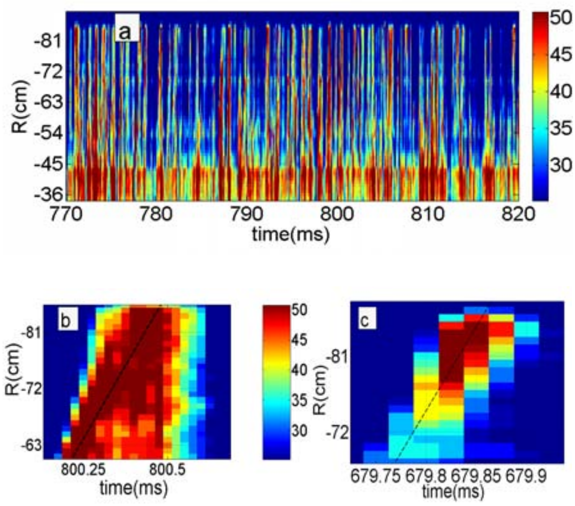

Fig. 5 Time evolution of the intensity of each pixel on the line in mid-plane (a); the radial motion of single blob-like structure (b, c). Shot No.: 3786.

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 μ s to 700 μ 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 1km/s in near the probe area. In the plasma source region, the radial velocity of blob-like structures is of V_b < 1km/s and in the vacuum region is of V_b > 1km/s.

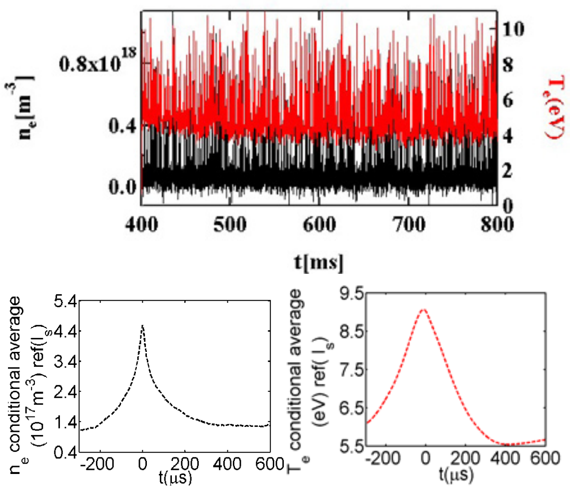

Fig. 6 top: Electron density (black) and electron temperature (red) from the Langmuir probe. bottom: Density (left) and temperature (right) conditional average (Ref: I_s > 0.3mA, t_a = 900μs). Shot No.: 3786.

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 × 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 μ 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 dependents 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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