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Behavior of edge plasma in STP-3M reversed field pinch

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Abstract

We have already reported that in an RFP plasma the energetic ions with the energy of about 3 keV are generated at magnetic reconnection. In this paper, the effect of these energetic ions on the behavior of the edge plasma is reported. In order to investigate the edge plasma, movable electrostatic probes scanning from the boundary of the core plasma to 122 mm outside are used. The energetic ions have a great influence on the behavior of the edge plasma. Even in the limiter shadow where energetic electrons concentrate, behavior of edge plasma greatly depended on the energetic ions.

Keywords: STP-3M; Boundary plasma; Reversed field pinch; Electric potential; Langmuir probe

1. Introduction

We have investigated the behavior of an RFP plasma in edge region by using movable Langmuir probes and a retarding potential energy analyzer (Faraday cup). We reported that in our RFP plasma energetic ions are emitted from the core plasma to the outside of the confined plasma at the magnetic reconnection [1].

In this paper, the effect of those energetic ions on the behavior of the edge plasma is reported. The behavior of the edge plasma is investigated by using movable electrostatic probes. Owing to the finite Larmor radius effect, measurements far from the confined plasma make possible to separate the behavior of the energetic ions and the electrons. As the results, the macroscopic behavior of the edge plasma is made clear. The energetic ions have a great influence on the behavior of the edge plasma. Even in the limiter shadow where energetic electrons concentrate, its behavior greatly depends on the energetic ions.

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2. Experimental apparatus

Experiments are carried out in STP-3M [2,3]. Its major and minor radii of the plasma are 0.5 m and 0.088 m, respectively. These experiments are carried out at plasma current of 60–100 kA. The current durations is 1–3 ms. The electron temperature and the density at the center are 100–500 eV and $1\text{–}4 \times 10^{13}$ cm^{-3}, respectively. The electron temperature at the edge plasma is 10–20 eV. The electron density at the edge is $10^{11}\text{–}10^{12}$ cm^{-3}. In STP-3M, semicylindrical molybdenum limiters are attached on the inner surface of the straight sections of the liner.

The behavior of edge plasma is measured by electrostatic probes. Triple probes, a combination of an electrostatic double and single probes, are installed at one of the horizontal diagnostic ports for the simultaneous measurement of ion and electron saturation currents and floating potential. Three tip electrodes of the probe are made of tungsten with 1 mm diameter and 1 mm length, separated by 5 mm each other. The probe can be scanned from $d = 4$ mm to 122 mm to the outward, where $d = 0$ corresponds to the plasma surface, and the position from $d = 0$ mm to 12 mm corresponds to the location just behind the limiter.

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The I–V characteristic of the probe is obtained by applying sawtooth voltage to the probe. The dc voltages applied to the probes, $V_p = -40$ V and 40 V, are in the ion and electron saturation regions, respectively. We adopted a simplified probe theory to the thermal edge plasma taking into account the effects of magnetic fields and secondary electron emission [4]. However, the ordinary sheath theory can not adopt to the energetic ions and electrons. The power spectra of electrostatic fluctuations during the RFP sustainment phase were analyzed by using the fast Fourier transform (FFT).

In order to investigate the relation between the electrostatic fluctuations and magnetic fluctuations, a toroidal flux is measured by the flux loop wound on the same toroidal plane where the Langmuir probes and the array of magnetic probes are located. All the measured signals are digitalized and recorded by the data acquisition system.

3. Experimental results

Fig. 1 gives the time evolutions of the electrostatic quantities, ion saturation current I_s^+, electron saturation current I_s^-, and floating potential V_f, at $d = 70$ mm far from the boundary of the core plasma, together with the

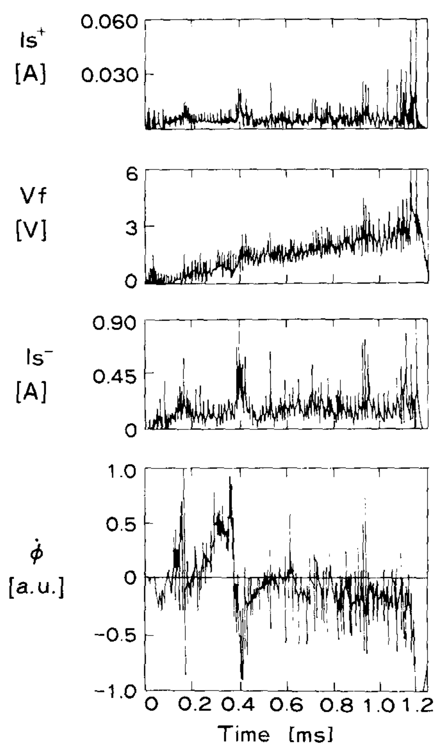

Fig. 1. Time evolutions of the electrostatic quantities, ion and electron saturation current, I_s^+ and I_s^-, and floating potential V_f at $d = 70$ mm, far from the boundary of the core plasma, together with a time history of the time derivative of toroidal flux $\dot{\phi}$.

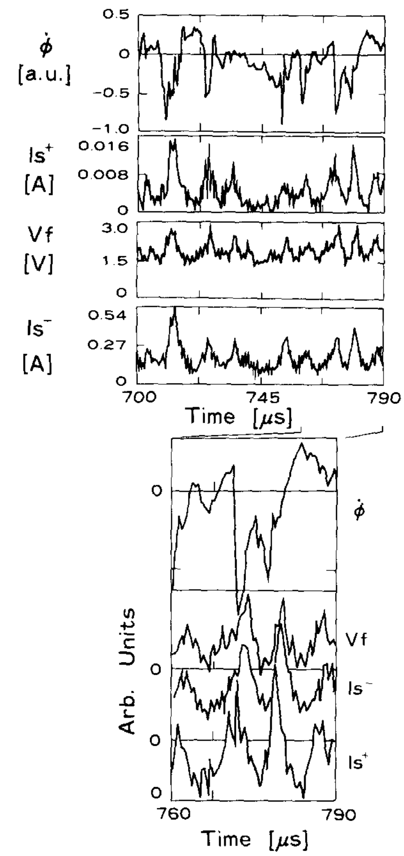

Fig. 2. Time evolutions of the electrostatic fluctuations and the toroidal flux fluctuation shown in Fig. 1 with expanded time scale.

time history of the time derivative of the toroidal flux $\dot{\phi}$. A lot of positive spikes are seen in these electrostatic quantities. The appearance of the positive spikes in the signal were also observed in HBTX-1A [5]. The floating potential begins to increase just after the setting up of RFP configuration and gradually increase in the positive direction. Fig. 2 shows the time evolutions of the above mentioned quantities with expanded time scale. It shows that just after the rapid decrease in $\dot{\phi}$, the ion saturation current intermittently increases. The floating potential increases in positive direction, as the ion saturation current increases. And then the electron saturation current increases. The increase in the ion saturation current is always observed earlier than that in the electron saturation current. The cross-correlation coefficient between the ion and electron saturation currents, compared with the auto power spectra of both of these saturation currents are shown in Fig. 3. The coherence is about 1 in their prominent power frequency regions. And the phase shift in Fig. 3 shows that the ion burst is observed earlier than the electron burst.

The intermittent increase in the ion saturation current at $d = 70$ mm is about 20–40 mA. The measurement by using the retarding potential energy analyzer shows that it

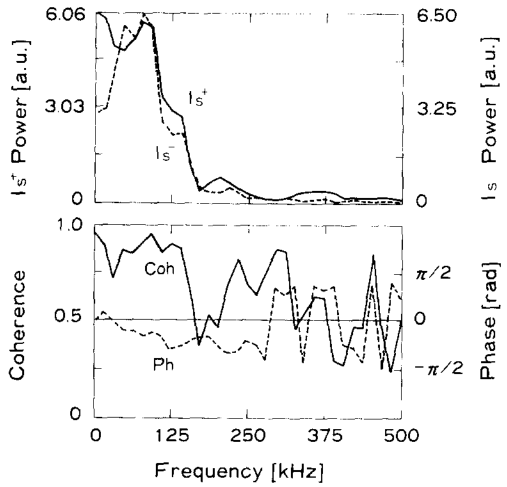

Fig. 3. The cross-correlation coefficient between the ion and the electron saturation currents, compared with the auto power spectra of both of these saturation currents.

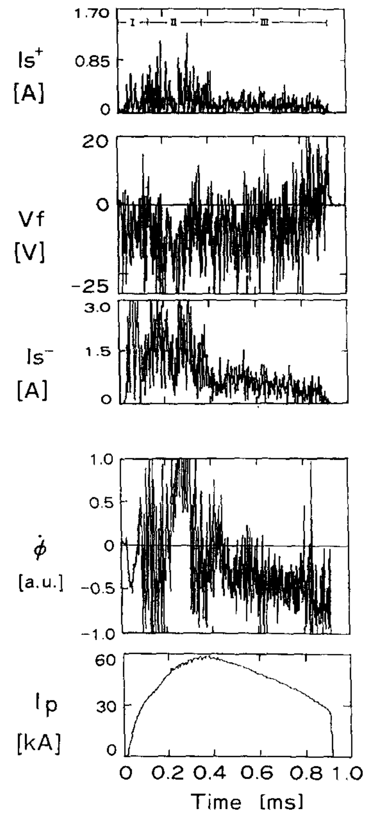

Fig. 4. Time behavior of toroidal flux $\dot{\phi}$, ion and electron saturation currents, I_s^+ and I_s^-, and floating potential V_f at $d = 4$ mm, just behind the limiter, together with plasma current I_p.

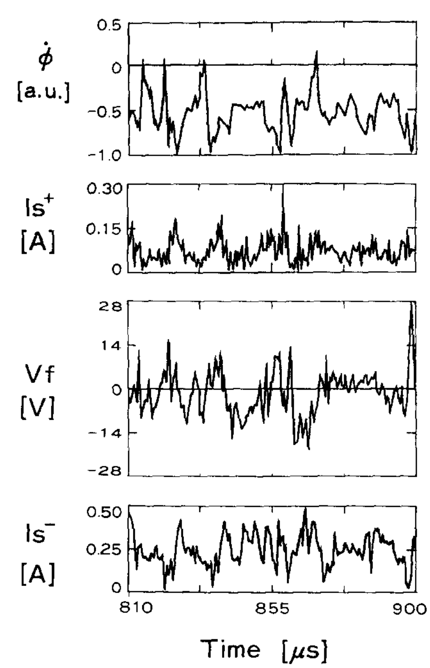

Fig. 5. Time evolutions of the electrostatic fluctuations and the toroidal flux fluctuation with expanded time scale.

is composed of the energetic ions with the energy of 3 keV [1]. Accordingly, the ion saturation current is not dependent on the electron temperature but on the drift velocity of the energetic ions. On the other hand, the slowly changing component correspond to the thermal ones, because the ratio of the slowly changing component of the ion saturation current to that of the electron saturation current nearly equal to 1:40.

The auto power spectra of the electrostatic fluctuations nearly coincide with that of $\dot{\phi}$. This suggests that the electrostatic fluctuations in the edge plasma greatly depend on the toroidal flux. The frequency at the peak power in the toroidal flux is about 60–120 kHz, which corresponds to that of the sawtooth oscillation.

Fig. 4 shows the time behavior of toroidal flux $\dot{\phi}$, ion and electron saturation currents and floating potential at $d = 4$ mm, just behind the limiter, together with plasma current I_p. Comparing with the fluctuations far from the edge plasma, large negative pulses generated by the high energy electrons with the monochromatic energy of 2–6 keV [6] are frequently observed in the floating potential. And a slowly changing component is negative, too. This suggests that the electron flow into the probe is more prominent than the ion flow. Fig. 5 shows the time evolutions of fluctuations with expanded time scale. As is similar to the evolutions of the fluctuations far from the plasma edge, just after decrease in $\dot{\phi}$, the ion saturation current starts to increase. When the ion saturation current follows the toroidal flux earlier than the electron saturation current, the floating potential increases positively. And then, rapid decrease to negative direction appears, as the electron saturation current increases. The time sequence of the behavior of the edge plasma observed behind the limiter shadow are same as that far from the boundary of the core plasma. This indicates that the energetic ions are emitted from the confined region.

At the later time ($t \sim 865$ μs) in Fig. 5, on the contrary, the increase in the electron saturation current is earlier than that in the ion saturation current. Behind the limiters, sometimes the burst of the ions is earlier than that of electrons, and sometimes the electrons do. Since each acceleration mechanisms are different, the ion and the electron heating is generated independently.

4. Summary

Many experiments have been carried out in order to investigate behavior of the edge plasma in an RFP. It has been pointed out that behavior of the RFP edge plasma is dependent on high energy electrons [7]. However, our results show that ions have a great influence to the edge plasma. In HBTX-1A, the same results was obtained [5]. Even in the limiter shadow where energetic electrons concentrate, it is found that the behavior of edge plasma is greatly dependent on the energetic ions. The results suggests that the energetic ions are emitted from the core plasma.

The time sequence between burst of the energetic ions and the dynamo is carefully investigated, the causality between the dynamo and the generation of the energetic ions is made clear. The ion heating does not coincide with the increase in the toroidal flux. It rather synchronized with both the decrease in it and the growth of the $m = 0$ modes [1]. This is self-consistent with that the auto power spectra of electrostatic fluctuations and $\dot{\phi}$ coincide with each other in 60–120 kHz region which corresponds to the sawtooth oscillation frequency.

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