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Control of Type-1 Intermittency Caused by Ion Acoustic Instability

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Abstract

We have experimentally attempted the control of intermittent chaos caused by the current-driven ion acoustic instability. When a positive pulse is applied to one of two mesh grids which are installed to excite the current-driven ion acoustic instability in a Double plasma, the instability is suddenly suppressed. On the other hand, when a negative pulse is applied, the chaotic state is well controlled with maintaining the instability.

Keywords:
controlling chaos, current-driven ion acoustic instability, drift velocity, OGY method, time-delayed feedback technique

1. Introduction

Recently, as a concept of chaos is universally understood, there has been an interest in the field of applied chaos, particularly, the controlling chaos has come to take notice in various dynamical systems. With regard to controlling chaos mainly two methods were famous, the first proposed by Ott, Grebogi, and Yorke (OGY) [1], and the second by Pyragas [2]. As a common characteristic of both methods, the point that the feedback technique is used for controlling chaos is cited. In plasma physics, chaos have been no longer rare phenomena, and frequently observed in instabilities concerning the plasma sheath, the discharge, and so on. On the other hand, the experiments on controlling chaos have been mainly performed for chaotic phenomena of ionization waves, so far [3], where the time-delayed feedback technique was used. Therefore, there have been no studies on the control of chaos caused by instabilities in a wave-plasma system so far. Recently, we observed the type-1 intermittent chaos caused by the current-driven ion acoustic instability (IAI) [4]. In this paper, we report the first experimental investigation on an attempt of the control of chaos caused by the current-driven IAI without the "external" feedback technique.

2. Experimental Apparatus

The experiments were performed using a Double Plasma (D.P.) device. The chamber and the measurement system are the same setting as our previous work [4]. Argon gases were introduced into the chamber with pressure of 4.0×10^{-4}Torr. Typical plasma parameters were as follows: the electron density $n_e \sim 10^8 cm^{-3}$, the electron and the ion temperature $T_e = 0.5$–1.5eV and $T_i \sim T_e / (10–15)$, respectively. In order to excite current-driven IAI, we installed two mesh grids G_1 and G_2 at interval L of about 2–5cm, and applied a dc potential V_m to G_1. Furthermore, the experiments on the control of chaos were performed by applying a positive or a negative pulse to G_2, where the pulse width and the amplitude $|V_p|$ were fixed at 2.0ms and 2.0V, respectively. The electron drift velocity v_d was

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measured using a directional rotatable probe, which was located in the center of the grids. Time series signals for chaotic analysis were obtained from fluctuating components of the currents I on G_1, and were sampled with a digital oscilloscope.

3. Experimental Results and Discussion

When dc potential V_m applied to G_1 exceeds a critical value, the current-driven ion acoustic instability (IAI) is excited between the grids G_1 and G_2. The instability was excited for $22.5 \leq V_m \leq 35$V. In the present experiments, V_m and L which are the control parameter of the IAI were fixed at 25V and ~ 3cm, respectively. Figures 1 show the typical variance of the time series (upper trace in each figure) and the power spectrum (lower trace), where Fig. 1(a) is only for the IAI signals, and Figs. 1(b)(c) are for applying the pulse with different polarities. In the case of applying a positive pulse, the IAI signals including turbulent bursts suddenly change to the small amplitude signals as soon as the pulse is applied, as shown in the upper trace in Fig. 1(b). These small amplitude signals are similar to one before the IAI is excited. On the other hand, Fig. 1(c) shows the case of applying a negative pulse. The time series signals change from the signals including turbulent bursts to the periodic one which has the same amplitude as the bursts, as shown in the upper trace in Fig. 1(c). Then, in order to investigate the variance of frequency components by applying a pulse, we carefully compared with the power spectra for each property of pulse. In the case of applying a positive pulse, as shown in the lower trace in Fig. 1(b), there are no discrete and broad peaks which are characteristic of the IAI [5]. Thus, these results suggest that the IAI is well suppressed by applying a positive pulse. On the other hand, in the case of applying a negative pulse, as shown in the lower trace in Fig. 1(c), the largest frequency peak (~ 80kHz) agrees with the fundamental frequency of the IAI, and the frequency spectrum become more coherent at the same time when the pulse is applied. Furthermore, higher harmonics remarkably appear. Thus, it is found that the frequency of the periodic signals is nearly ~ 80kHz. Note that the power spectrum for a negative pulse still keep the characteristic of the IAI.

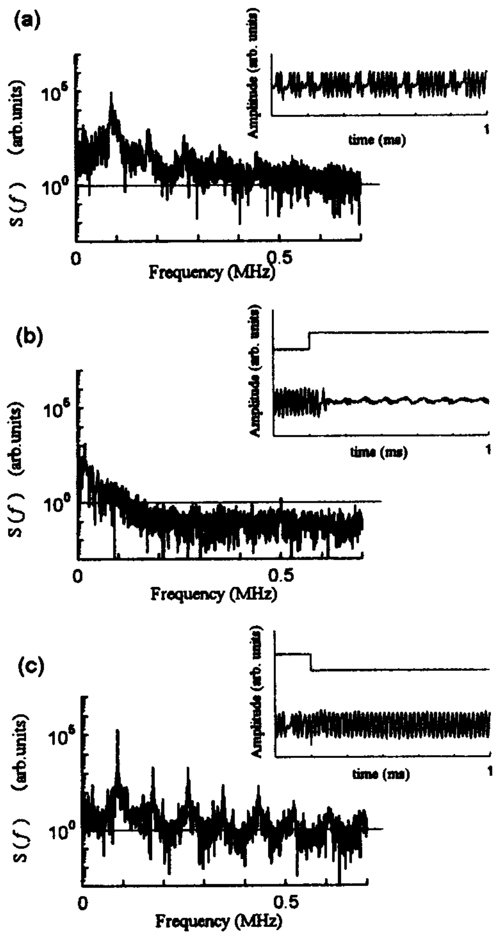

Fig. 1 Time series (top trace) and power spectra (down trace) for $|V_p| = 2.0$V. (a) before applying a pulse, (b) applying a positive pulse and (c) applying a negative pulse, where V_m = 25V, and L ~ 3cm.

In order to quantitatively evaluate the influence of applying a pulse on the system of the current-driven IAI, we measured the electron drift velocity v_d, which is a significant parameter to excite the IAI. The solid and open circles indicated in Fig. 2 show the typical variance of v_d / c_s as a function of V_m before and after applying a positive pulse with $|V_p| = 5$V, respectively, where c_s is the ion acoustic velocity. With increasing V_m before applying a pulse, v_d / c_s suddenly increases for $V_m = 25$V, and then $v_d / c_s \sim 20 - 30$ for $V_m = 25 - 35$V. The value of measured drift velocities agree with the numerical results obtained from the kinetic theory [6]. Where the excited region of the IAI is $v_d / c_s \geq 18$ for $T_e / T_i = 13$. The solid and open boxes in Fig. 2 show the drift velocity in the case of applying the pulse with different polarities. In the case of applying a positive pulse (solid box), the drift velocity decrease to $v_d / c_s \sim 6$, and as a result the current-driven IAI can not be excited. It is also found that the instability is well suppressed by applying a positive pulse. On the other hand, note that in the case of applying a negative pulse

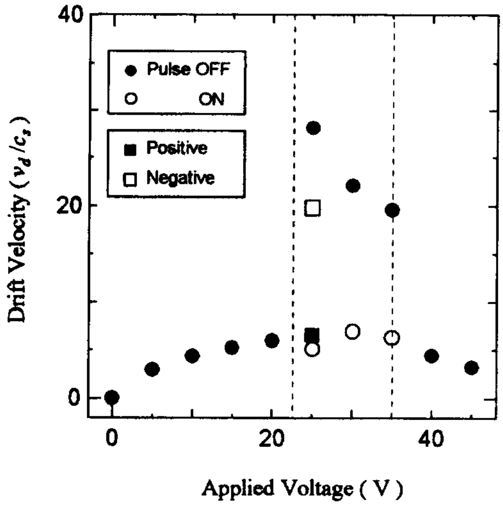

Fig. 2 The electron drift velocity v_d / c_s as a function of V_m. Where solid circle and the other symbols show before and after applying a pulse, respectively, and L ~ 3cm. The dotted lines denote the lower and upper limit for the excitation of the current-driven IAI

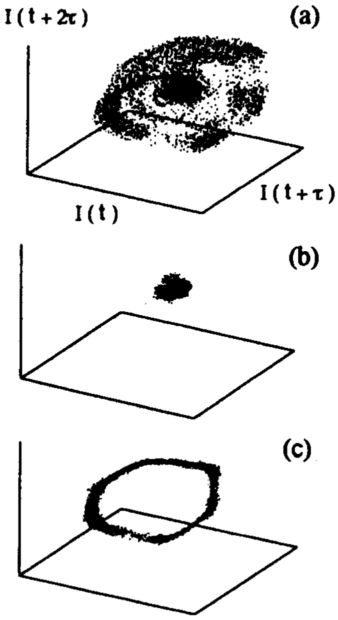

Fig. 3 The reconstructed trajectories on phase space. (a) before applying a pulse, (b) applying a positive pulse and (c) applying a negative pulse, where V_m = 25V, L ~ 3cm, the sampling time Δt = 1.0 × 10^{-6}s, and the time delay τ = 10Δt.

(open box), the drift velocity v_d / c_s ~ 20, suggesting that the current-driven IAI is theoretically still excited, though turbulent signals of the IAI change to the periodic one by applying a negative pulse, as shown in Fig. 1(b).

In the present experiments, it is confirmed that for 22.5V ≤ V_m ≤ 35V, the instability is excited and the system becomes a chaotic state. For example, as shown in Fig. 3(a) before applying a pulse, the reconstructed trajectory on phase space shows a strange attractor. In addition, its the correlation dimension D and the largest Lyapunov exponent λ_1 are D = 2.51 and λ_1 = 0.16, respectively, thus, the system is at a chaotic state. In order to investigate the influence of applying a pulse on the chaotic system from the chaotic point of view, we performed chaotic analysis from the time series which correspond to the duration time of the pulse. Figure 3(b) shows the reconstructed trajectory in the case of applying a positive pulse. As shown in this figure, the trajectory is converged and behaved randomly. Then, since D does not saturate and continues to increase in spite of increasing the embedding dimensions, and the largest Lyapunov exponent takes a negative value, λ_1 ~ −0.013. Thus, the system is changed from a chaotic state to so-called "white noise" state by applying a positive pulse. On the other hand, as shown in Fig. 3(c) in the case of the negative pulse, the trajectory shows a limit cycle. Furthermore, the system takes $D \simeq 1$, λ_1 ~ 0.0001. These results suggest that the system become a periodic state, as expected from the periodic time series signals shown in Fig. 1(c). Consequently, the current-driven IAI is well suppressed at the same time when the drift velocity decreases by applying a positive pulse, and then chaotic state caused by the IAI also vanishes. On the other hand, note that the system is changed from chaotic state periodic state by applying a negative pulse, with maintenance of the IAI in the system.

Here, we discuss about the mechanism of above phenomena observed by applying a negative pulse. The control of chaos means that unstable periodic orbits embedded in the chaotic attractor are stabilized to periodic orbits. Therefore, it is concluded that the control of chaos is well achieved by applying a negative pulse. In the current-driven IAI, the existence of a feedback mechanism for unstable wave between the grids is well known [5]. Thus, the reason why chaos caused by the IAI is controlled by applying a negative pulse may be explained by means of the follow scenario. When a negative pulse is applied to G_2, at least the dc electric field between the grids does not decrease in comparison with that before the pulse is applied. Thus, since the electron drift velocity does not decrease, the current-driven IAI is maintained. Consequently, applying a negative pulse influences on the feedback mechanism of the unstable wave with information of chaos, and as a result chaos is controlled. These results are consistent with the fact that the frequency of the periodic orbits selected when the chaos is controlled agrees with the fundamental frequency ~ 80kHz of the IAI, which is determined by the interval L between the grids. This controlling method suggests a possibility of controlling chaos in the plasma instabilities with a *inherent* feedback mechanism.

4. Conclusions

We examined the control of chaos caused by the current-driven ion acoustic instability by applying a pulse to one of two mesh grids which are installed in a Double Plasma. When a positive pulse was applied, the electron drift velocity υ_d / c_s rapidly decreased and the current-driven IAI was well suppressed. Therefore the chaotic system also vanished and became the so-called "white noise" state. On the other hand, when a negative pulse was applied, υ_d / c_s hardly changed and thus the IAI was maintained. However, the state of the system changed from chaotic orbits to periodic orbits, whose frequency agrees with the fundamental frequency of the IAI. Consequently, these results suggest that the control of chaos is achieved by applying a negative pulse.

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