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Control of Intermittent Chaos Caused by Ion Acoustic Instability

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Abstract

The control of intermittent chaos caused by the current-driven ion acoustic instability is attempted and the controlling mechanism is investigated. It is found that when a negative DC-voltage is applied, the system changes from chaotic state to periodic state with maintaining the instability, showing that the chaotic state caused by the instability is well controlled by applying a negative DC voltage. Furthermore, it is found that hysteresis is observed on the V-I curve of the mesh grid where the DC voltage to control chaos is applied.

Keywords:
nonlinear phenomena, intermittent chaos, controlling chaos, hysteresis, ion acoustic instability

1. Introduction

Ott, Grebogi, and Yorke (OGY) [1] firstly proposed a general way to control chaos using a feedback system. Thereafter, the OGY method was experimentally and theoretically modified to realize the control of chaos in real systems by many authors, so far. Pyragas [2] suggested a time-delayed feedback technique, which is more appropriate for the experiment than the OGY method. However the experiments on controlling chaos in plasma have, so far, been only performed for chaotic phenomena in the DC discharge system [3-6]. These experiments were mainly carried out using the Time-Delayed Auto Synchronization (TDAS) method [3,7] or the modified OGY method. We have observed that the system becomes chaos via the type-1 intermittency [8] caused by the current-driven ion acoustic instability (IAI) which is one of typical instabilities in a plasma [9], and succeeded in controlling chaos by applying a negative pulse [10]. Here, we attempted to make the mechanism of control clearer. Especially, experimental results of controlling chaos by applying a negative DC voltage are reported. Furthermore, exciting of driven-chaos by applying a negative DC voltage is reported.

2. Experimental Apparatus

The experiments were performed using a Double Plasma device [11] whose dimensions were 70 cm in diameter and 120 cm in length. Here, the plasma was produced by DC discharges between tungsten filaments and a chamber wall only in the *target* region on this work. The chamber was evacuated to 4.0×10^{-7} Torr, and then argon gases were introduced into the chamber with pressure of 4.0×10^{-4} Torr. Typical plasma parameters were as follows; the electron density $n_e = 10^8$ cm^{-3}, the electron and the ion temperature $T_e = 0.5–1.0$ eV and $T_i = T_e/(10–15)$, respectively. In previous work [9], the current driven IAI was excited by the

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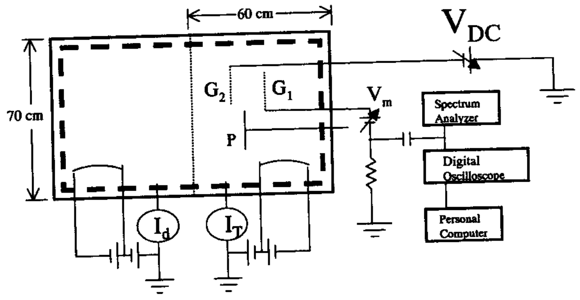

Fig. 1 Schematic diagram of the experimental apparatus.

measurement system that two parallel mesh grids were installed, and two mesh grids G_1 and G_2 whose dimensions are 6 cm in diameter and 50 mesh/in. at interval L of 2 – 5 cm. A DC potential V_m was applied to G_1 in order to excite IAI. Furthermore, the experiments on the control of chaos were performed by applying a positive or a negative DC voltage "V_{DC}" to G_2, as shown in Fig. 1 and time series signals for analysis were obtained from the fluctuating components of the currents on the V_m biased mesh grids, and were sampled with a digital oscilloscope.

3. Experimental Results and Discussion

The current-driven ion acoustic instability (IAI) was excited by inverse electron Landau damping which is caused by the relative motion of electrons against ions [12]. Here, V_m and L which were the control parameters of the IAI were fixed at 23 V and 3 cm, respectively. Fig. 1(a) shows the typical chaotic state before controlling, the power spectra and the time series signals, reconstruct trajectories on phase space using the embedding method [13]. From time series signal, the characteristic of the IAI signals that include turbulent bursts was observed. Then, we performed chaotic analysis from time series in absence of controlling in order to evaluate whether the system before controlling is chaotic or not; the calculations of the correlation dimension and the Lyapunov exponent were performed. In the former calculation the method of Grassberger and Procaccia [14] was used, and in the later that based on Wolf's algorithm [15] was used. As a result, we confirmed that the system in absence of controlling is chaotic state, since the value of correlation dimension was non-integer and the largest Lyapunov exponent was positive, which is the characteristic of the chaotic state. In previous work [10], we succeeded in controlling chaos by applying a pulse, however, in this work, we used a DC voltage instead of a pulse, because the frequency of the pulse is sufficiently smaller than the fundamental one of IAI.

It was found that when a positive voltage was applied to one of two mesh grids which were installed in a plasma, the instability was suddenly suppressed above

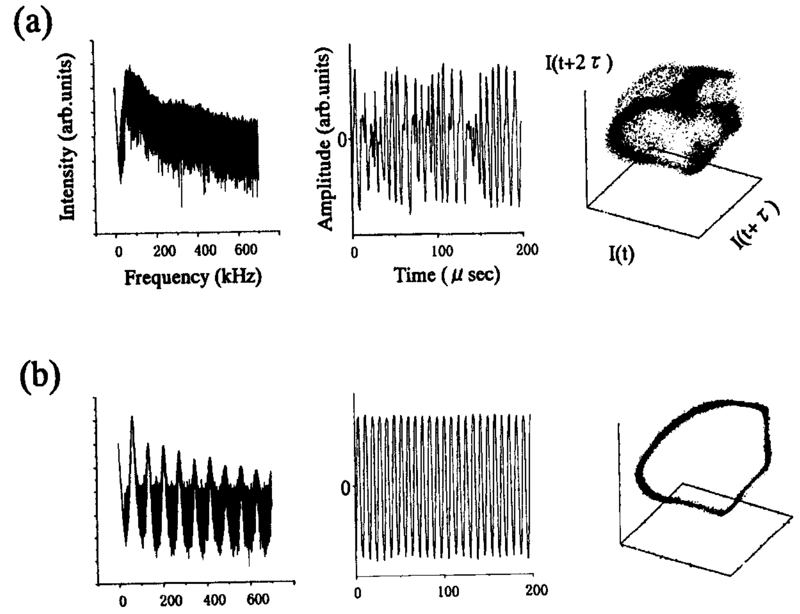

Fig. 2 The change of the system by applying a negative voltage. Power spectra, time series and reconstructed orbit are illustrated, respectively, (a) before applying, (b) above a threshold.

a threshold (+3 V). On the other hand, as shown in Fig. 2, when a negative voltage was applied, the system changed from chaotic state to periodic state above the threshold (–3 V). For the periodic state, Fig. 2(b) shows that the instability is maintained. These results indicate that the chaotic state caused by the instability was well controlled by applying a negative voltage, without directly using well-known OGY method [1] and TDAS method [3,7].

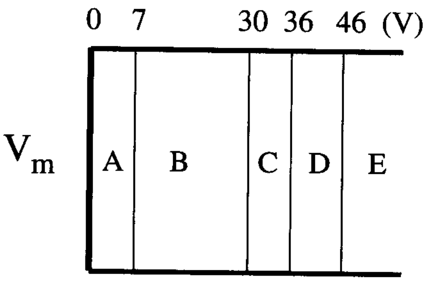

Fig. 3 The change of the system against the parameter V_m; A: before exciting IAI, B: IAI, C: periodic state, D: IAI, E: vanishing of IAI.

Furthermore, under these experiments, we observed that the system becomes the state where periodic component was dominant in some parameter's region. In Fig. 3, the change of the system is illustrated against the parameter V_m. IAI is excited in B and D region, and the system becomes periodic in C region. Then, when we apply a negative voltage to C region in the same way, as shown in Fig. 4, the system becomes the chaotic state (c) via the bifurcation, where the applied negative voltage is a control parameter. For chaotic state (c), "driven-chaos" [16] was excited, because the system became chaotic via the bifurcation and the fundamental frequency was about 140 KHz, which was completely different from IAI's one (about 70 KHz). Sampling the unstable states with period-3 are our future works.

4. Conclusion

The control of intermittent chaos caused by the IAI was attempted by applying DC voltages. When a positive voltage was applied to one of two mesh grids installed in a plasma, the instability was suddenly suppressed. On the other hand, when a negative voltage

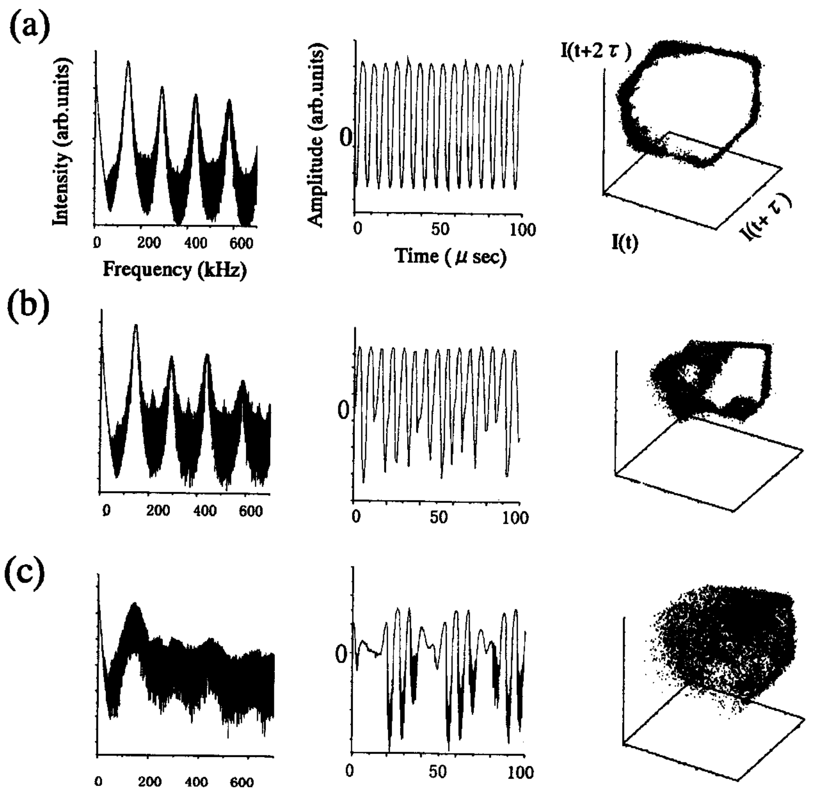

Fig. 4 The change of the system by applying a negative voltage V_{DC}, Power spectra, time series and reconstructed orbit are illustrated respectively, (a) before applying, (b) period-doubling, (c) chaotic state.

was applied, the system changed from chaotic state to periodic one with maintaining the instability, showing that the chaotic state caused by the instability was well controlled by applying a negative voltage. Furthermore, when we applied a negative voltage to the system where periodic components were dominant, the system became chaos via the bifurcation.

Thus, interesting phenomena that the applying negative DC voltage leads to controlling chaos while exciting driven-chaos was found.

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