THE CHAOS CONTROL IN PARAMETRIC DECAY INSTABILITY OF STIMULATED BACKSCATTERING BY A PUMP FREQUENCY MODULATION

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The chaotic behavior of nonlinear three-wave system in which the inhomogeneous plasma absolute parametric decay instability of stimulated backscattering l → l' + s is excited is investigated. The possibility of transition three-wave system from chaotic to regular behavior under influence of pump frequency modulation is demonstrated experimentally.
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1. INTRODUCTION

Over the past decade, the problem of chaos controlling in plasmas attracted significant attention due to the importance of this topic for many processes in plasma physics [1-3]. In addition to the general interest of this subject the studies were motivated by the possibility of reduction of the anomalous transport, associated with plasma turbulent phenomena. It is well known that almost all systems reach turbulent state via chaos development, therefore, investigation of chaos control may contribute to understanding and control of the turbulence in plasma processes. The main idea in controlling chaos is to use the high sensitivity of the system to small perturbations to change the dynamical state. Based on this approach, several effective methods of chaos control have been proposed by Ott, Grebogi, and Yorke (OGY) [4] and Paragas (TDAS) [5].

In this paper we demonstrate experimentally the possibility of three-wave system transition from chaotic to regular behavior under influence of the pump frequency modulation without directly using the well-known OGY and TDAS methods. We perform studies using the wave system in magnetized inhomogeneous plasma in which absolute decay parametric instability of stimulated backscattering $l \rightarrow l' + s$ is excited at linear stage [6].

2. EXPERIMENTAL SITUATION

Experiments were carried out at the linear plasma device with magnetic field of 0.35 T, in which inhomogeneous plasma ($n_e=n_e(z,r)$) was produced by ECR discharge in argon at pressure 1-2 Pa [6]. The electron plasma pump wave at frequency f_0 = 2.5-2.7 GHz – (EPW) – was excited in this plasma using a waveguide system. In vicinity of resonant (focal) point, where $n_e(z,0)=n_c$ (i.e., $2\pi f_0=\omega_p=(2\pi n_e e^2/m_e)^{1/2}$), the electric field of the electron plasma wave increases.

The growth of electric field in the vicinity of focal point is so significant, that an absolute parametric decay instability of stimulated backscattering $l \rightarrow l' + s$ is excited at the relatively small pump wave power P_0 exceeding 20 mW. This instability was studied previously in experiments with monochromatic pump wave [6]. The instability excitation mechanism, according to [6], is related to the complicated spatial structure of pump wave, namely to the small fraction of the first radial mode present in the pump along with the dominant fundamental radial mode ($P_1 \leq 0.1P_0$) The first radial mode leads to appearance of the second resonance region of the three-wave interaction and to the formation of the feedback loop. An instability growth rate and an unstable spectrum structure are determined by velocity of the ion-sound wave and the feedback loop dimension. At the linear stage the absolute decay instability is a coherent process with the limited number of oscillatory modes excited, which should possess a narrow frequency spectrum.

However in reality both the spectrum consisting of several narrow lines and broad spectrum are observed depending on the plasma parameters connected with each other (density and temperature of plasma components, pump power and its frequency width, external magnetic and etc). High sensitivity of the absolute instability to the incident pump power is observed at small excess of its threshold ($P_0 \geq 20$ mW), when the parametrically scattered emission is increased by 2-3 orders of magnitude at the rise of the pump power by a few percents.

As it was shown in [7], it is possible to influence the absolute parametric decay instability of stimulated backscattering using a harmonic pump frequency modulation. It was demonstrated in this paper that the stimulated backscattering can be suppressed by several orders of magnitude by modulation at frequency f_m = 1 MHz with deviation not exceeding ±1-2% of pump wave frequency (f_0 = 2350 MHz). It should be mentioned that the stimulation of absolute parametric instability was also observed in this experiment at modulation frequency f_m ~0.2 MHz [7]. In both cited papers only the backscattering power spectra were under investigation whereas in the present paper we consider the temporal variation of backscattering signal and acoustic wave, paying special attention to proper characterization of $l \rightarrow l'+s$ three-wave dynamic system.

In the pump frequency modulation experiment the decay ion acoustic wave was studied by enhanced scattering technique [7]. For this purpose the probing wave at frequency f_p = 2.35 GHz < f_0 and small power (P_p < 5 mW) was launched into plasma by the same waveguide system. In vicinity of the own resonance point the probing wave is effectively scattered off the parametrically driven ion-sound wave. The scattered wave amplitude, proportional to the ion–sound one, was used after homodyne detection for studying the dynamics of the three-wave system. The homodyne detector signal was digitized by means of an 8 bit A/D converter with time quantization Δt = 0.025 µs. The obtained scalar time series were used for creation of the system phase space and investigation of its attractor.

3. EXPERIMENTAL RESULTS AND DISCUSSION

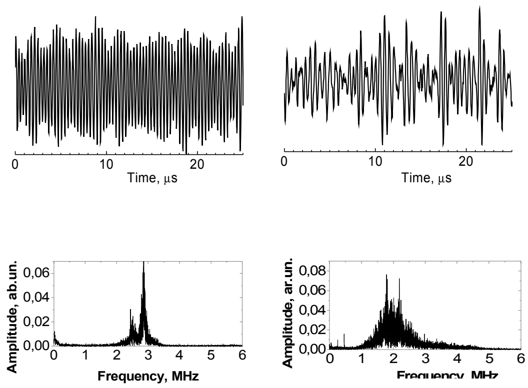
The following pump wave modulation parameters were used in the experiment: the central frequency f_0 = 2600 MHz, modulation frequencies f_m = 0.2 MHz and 1 MHz, maximal frequency deviation δf = ±35 MHz.

The homodyne detector signals for two pump powers are presented in fig. 1a. The left waveform corresponds to the pump power P_0 = 30 mW that is close to the excitation threshold P_{th} =20 mW. The right waveform is obtained at pump power P_0 = 50 мВт when a substantial anomalous reflection due to the decay instability takes place. The power spectra corresponding to these signals are presented at fig. 2b. As it is seen, significant broadening of ion acoustic wave spectrum takes place with growing pump power. The spectral broadening indicates the increasing chaos level in the three-wave system dynamics. This conclusion is confirmed by analysis of the system phase space performed in fig. 1c, where trajectories corresponding to the two waveforms are shown. As it is seen at lower pump power 3D trajectories create the torus in the phase space, whereas at greater power they occupy all the space.

At the quantitive level this difference is characterized by the attractor dimensions. The estimation of the attractor dimension D was obtained in accordance with [8]. The correlation dimension of attractor is given by derivative D = d(ln C(r))/d(ln r), where C(r) – correlation integral, giving the number of points in the phase space in the sphere of radius *r*. The dependencies of correlation dimension of attractors D on the sphere radius calculated for different dimensions of phase space (n = 1÷5) are presented in fig. 1d. As it is seen in the left figure, at lower power there is a wide range of the sphere radii, where the attractor dimension is about 1.7 independent on the phase space dimension. This number gives the

a

b



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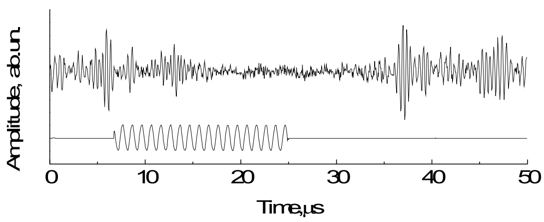

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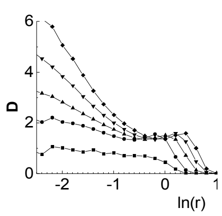

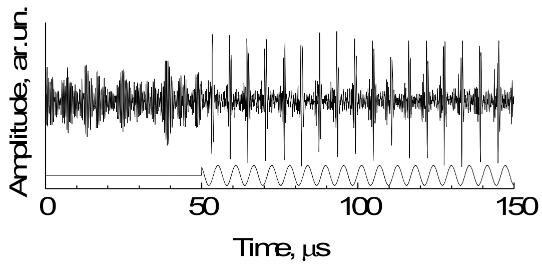

Fig. 1. The homodyne
attractors (d) in case
30 mW, right one – 50 mW

Fig. 2. Oscillograms of the homodyne (a) and control (b) signals at modulation frequency 1 and 0.2 MHz correspondingly

estimation of the real attractor dimension, which is rather low and corresponds to quasi-periodic character of the three-wave decay system dynamics at this pump power level. At the higher pump power, as it seen in fig. 1d (right), the attractor dimension is increasing continuously with dimension of the phase space. This behavior is similar to that computed for trajectory reconstructed from a noise-like signal. This observation is probably explained by the chaotic fluctuations introduced into the three-wave dynamic system due to its very high sensitivity to the pump and plasma parameters. One of such parameters is the pump frequency deviation.

The homodyne detector signals at harmonic pump frequency modulation are presented in fig. 3 together with the corresponding control signals of the sweep oscillator.

As can be seen in fig. 2a, at modulation frequency ~1 MHz a suppression of absolute parametric instability takes place. On contrary, at modulation frequency f_m ~0.2 MHz the instability stimulation, shown in Fig. 2b, is observed. As it is seen, the homodyne detector signal changes drastically when the modulation is switched on. The bursts of oscillations, which were random before the modulation onset are evidently synchronized by the control signal. The amplitude of these bursts is substantially higher. This effect is explained by the suppression of convective losses of ion acoustic wave from the decay region, which takes place periodically for specific relation between the modulation rate and frequency [9]. Such a suppression occurs when velocity of the decay point oscillating in plasma at the modulation frequency f_m = 0.2 MHz coincides with the ion acoustic wave velocity. The burst of oscillations takes place once per modulation period and is followed by its deep suppression.

a

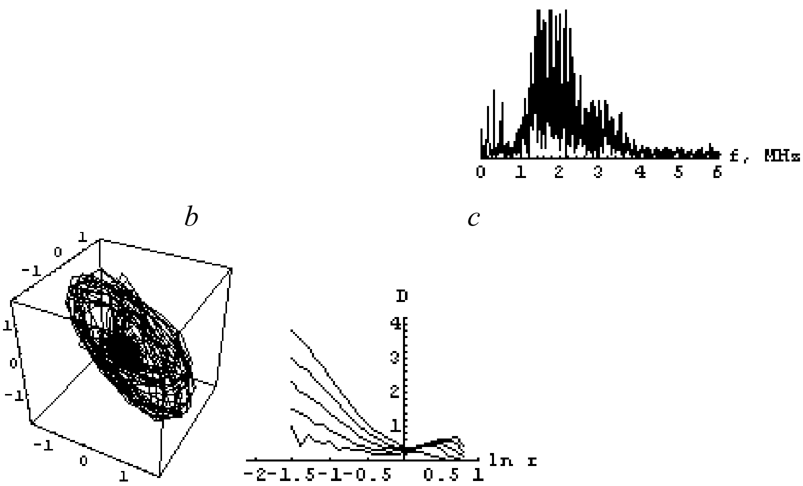

Fig. 3. Power spectra (a), attractors (b) and correlation dimensions of attractors (c) in case of frequency modulated pump wave

The homodyne detector signal power spectra, 3D attractor and the procedure of its correlation dimension estimation after switching on of the modulation in the last case are shown in fig. 3. It is found that the system changes from chaotic to quasi periodic state.

Summarizing we can conclude that the harmonic pump frequency modulation provides an effective way for control of chaos in a nonlinear dynamic three-wave system $l \rightarrow l' + s$.

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УПРАВЛЕНИЕ ХАОСОМ В ПАРАМЕТРИЧЕСКОЙ РАСПАДНОЙ НЕУСТОЙЧИВОСТИ ВЫНУЖДЕННОГО РАССЕЯНИЯ НАЗАД ПРИ ЧАСТОТНОЙ МОДУЛЯЦИИ НАКАЧКИ

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Нелинейная трехволновая система, приводящая к абсолютной параметрической неустойчивости вынужденного рассеяния назад в неоднородной замагниченной плазме исследуется относительно состояния динамического хаоса. Экпериментально продемонстрирован переход трехволновой системы из состояния хаотического поведения в регулярное с помощью гармонической частотной модуляции волны накачки.

КЕРУВАННЯ ХАОСОМ У ПАРАМЕТРИЧНІЙ РОЗПАДНІЙ НЕСТІЙКОСТІ ЗМУШЕНОГО РОЗСІЮВАННЯ НАЗАД ПРИ ЧАСТОТНІЙ МОДУЛЯЦІЇ НАКАЧУВАННЯ

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Нелінійна трихвильова система, що приводить до абсолютної параметричної нестійкості змушеного розсіювання назад у неоднорідній замагніченій плазмі досліджується щодо стану динамічного хаосу. Експериментально продемонстровано перехід трихвильової системи зі стану хаотичного поводження в регулярне за допомогою гармонійної частотної модуляції хвилі накачування.