NEW INVESTIGATIONS ON THE DYNAMICS OF EXTERNALLY PERTURBED STATES OF A CHAOTIC DISCHARGE-PLASMA DOUBLE LAYER

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This work presents new results of the investigations on the dynamics of double-layers (DLs) generated in a discharge-plasma system under external perturbations. In different ranges of the control parameter the dynamics of the DL structure can present different behaviors. The transition from a chaotic state to other one, due to a perturbation, can be controlled by the parameters of this perturbation. In certain conditions the DL-resulting state can be periodic or not. The experimental results are in agreement with the predictions of a model based on coupled Van der Pol oscillators.

1. Introduction

In many cases, the behavior of the plasma devices is chaotic. The principles of the control of this behavior were established in many works (e.g. [1,2]) based on the general theory of the dynamical systems. In the particular situation of a discharge-plasma containing double layers it is shown that transitions from chaotic dynamics to a periodic one can be induced also by random noise [3]. Based on a phenomenology of coupled Van der Pol oscillators some results of a modeling of the perturbed dynamics of a DL-plasma system were presented in [4]. In the same idea, this paper presents some new results of a more detailed study on a perturbed discharge plasma DL. So, there is performed the continue variation of the control parameter and there is observed, specially, the transition of the DL dynamics from periodic to chaotic (and vice–versa) states. Of course, this gives the possibility to investigate more in depth the control of the chaotic behavior of the DL for different values of the amplitude or frequency of the harmonic perturbation [5] in another way than the trivial one of dc biasing control. Also, a numerical model is proposed.

2. Experimental procedure and results

The experimental device consists of two short adjacent glow discharges, with plane cathodes and cylindrical anodes, all placed in the same glass tube (100 cm length, 8 cm inner diameter), in argon at low pressure. The DL is formed at the contact region of the two glow discharge plasmas, between the two anodes A_1 and A_2 (distanced at 40 cm) that are biased one against the other by a dc power supply whose voltage U_m is considered as the experimental control parameter. Other details of the experimental set-up are given in [4,6,7].

A perturbed regime (as a test on the DL stability, or for controlling possible chaotic states of this space charge structure) is realized when a sinusoidal potential difference U_p is supplementary super-imposed to bias the two coupled discharges. In fact, U_m assures the appearance of a given DL while U_p, due to its characteristics, can control the dynamics of the DL. The current I_{12} flowing through the DL-forming region is taken as global observing parameter for description of the DL dynamics. In such experimental conditions, adequate methods (including digital acquisition one) as space–time diagrams, phase-plane plots, frequency spectra, and other types of measurement on the

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plasma parameters are performed to investigate the DL dynamics [5-8].

Increasing the biasing potential U_m, slightly above the ionizing potential of the working gas, periodical oscillations of the current I_{12} are observed first. These oscillations are correlated with the dynamics of the DL appearing in the above described plasma [4,6]. The space-temporal pattern of the DL–evolution depends on the value of the dc biasing voltage U_m and other experimental parameters (gas pressure, supply currents, etc). In Fig. 1a a time-averaged I_{12}-U_m current–voltage characteristic of the A_1A_2 discharge interval is presented. Also, in Fig. 1b and Fig. 1c there are presented amplitude-frequency spectra and a corresponding spectrogram of the I_{12} current oscillations versus the dc U_m biasing voltages, respectively. On these spectra, for higher U_m values, windows of periodic (including sub-harmonics sequences) and chaotic DL plasma behaviors there are observed.
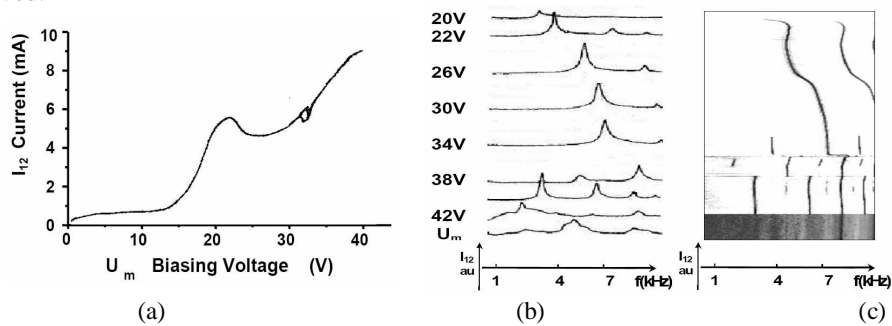

(a)   (b)   (c)

Fig. 1. a) Averaged I_{12}-U_m volt-amperic characteristic. b) Experimental amplitude spectra of the I_{12} current for different values of   the U_m biasing   voltage   and   a   corresponding spectrogram (c).

Now, trying to control (in a different manner then modifying dc U_m biasing voltage) the chaotic states of the DL containing plasma the supplementary biasing voltage U_p is applied. For a given chaotic state (fixed by a value of U_m), the type of the perturbed DL-dynamics depends on the parameters of the perturbing voltages. The temporal pattern of evolution also depends on the value of the dc biasing voltage for the fixed DL-state and other experimental parameters (gas pressure, supply currents, etc.). The spectrograms of $\tilde{I}_{12}$ versus U_m in Fig. 2 show the appearance and the domains of ordered and disordered states for the harmonically forced DL-structures. The grey scale colors show the amplitude for a given frequency (white is the lowest level (-90 dB) and black is the highest level
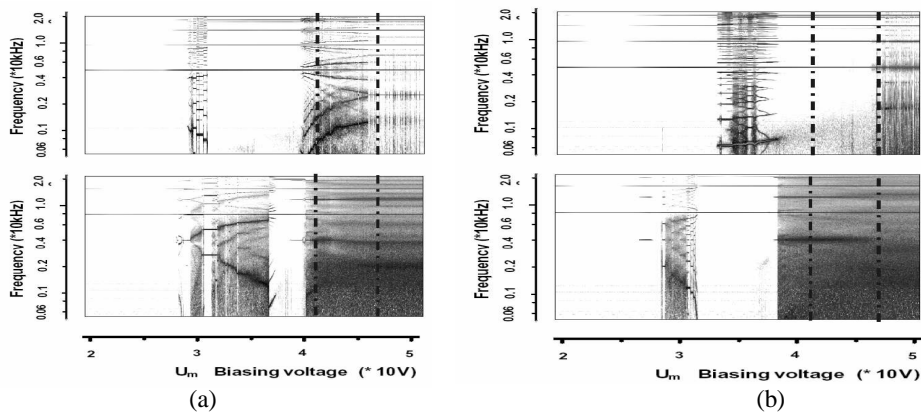

(a)   (b)

Fig. 2. Spectrograms of $\tilde{I}_{12}$ oscillations versus the U_m biasing voltage. Gas pressure – 45 mTorr, forcing frequency: 5kHz – upper diagrams, 8 kHz – lower diagrams, left (a) - $U_p = 5V_{vv}$,   right (b) - $U_p = 10V_{vv}$, (0dB)). Here, different traces represent the appearance and the evolution of different "spectral lines" of the $\tilde{I}_{12}$ oscillations with increasing of the dc biasing voltage. A uniform blackish domain is a region of chaotic behavior. As it is expected, for chaotic domains   the   low frequencies   are predominant. The left dotted lines on each spectrogram give the limit of a second chaos large region in the non-perturbed situation.

For an initial chaotic state, depending on the amplitude and the frequency of the U_p, ordered or disordered behaviors can be observed. This demonstrates the possibility (giving the domains of the control parameter) of control of the DL dynamics. The fact is revealed also from Fig. 3 where a slice (spectrum) of the $\tilde{I}_{12}$ oscillations at a value U_m indicated by the right side broken line in Fig. 2a is put together with the corresponding phase-plane plot.
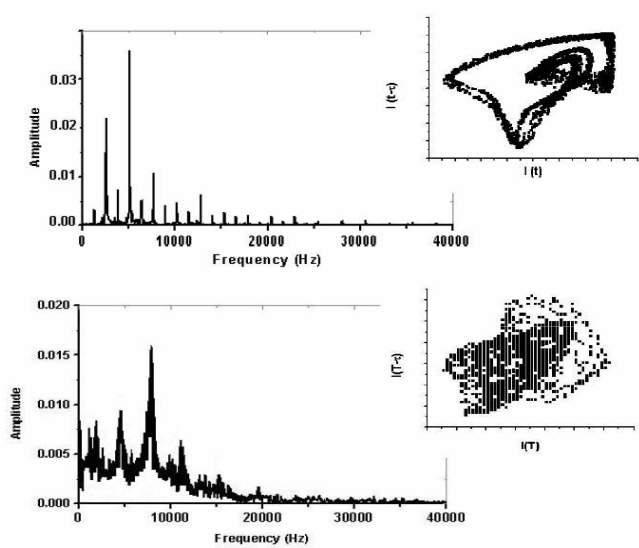

Fig. 3. $\tilde{I}_{12}$ FFT-amplitude spectra and the corresponding $\tilde{I}_{12}(t)$-$\tilde{I}_{12}(t-\tau)$ phase-plots showing periodical (upper) and chaotic (lower) states for perturbed chaotic DL-plasma system relative to the positions indicated in Fig. 2a by right broken lines on upper and lower spectrograms.

3. Mathematical model and numerical simulation

The model consists in a modified version of a system of two coupled Van der Pol oscillators corresponding to the two discharges coupled by a dc biasing on which a sinusoidal perturbation is superimposed [4,5]. The model equations are:

$$\begin{cases} \dot{x}_1 = x_2 + mx_4 \\ \dot{x}_2 = -c(x_1^2 - 1)x_2 - x_1 + e\cos x_5 + m(x_4 + x_3) \\ \dot{x}_3 = x_4 - mx_2 \\ \dot{x}_4 = -f(x_3^2 - 1)x_4 - x_3 - e\cos x_5 - m(x_2 + x_1) \\ \dot{x}_5 = 2\pi g \end{cases} \qquad (1)$$

Here, the variables x_1, x_3 stand for the flowing currents while x_2, x_4 represent voltages. The variable x_5 is the phase of the sinusoidal perturbation with g – taken as frequency of the perturbation. The characteristics of the two coupled discharges are included in the nonlinearity constants c and f, while the biasing potential U_m is related to the coupling m – taken as theoretical control parameter. The periodic forcing term, with amplitude e and frequency g, is introduced in a conventional way and corresponds to the ac perturbing supply U_p [9].

Results of the numerical model are presented in Fig. 4, as bifurcation diagrams of the variable x_1 versus m for different values for the amplitudes e of the harmonic perturbation. Also, like in the experimental data results (see Fig. 3– upper graph), in Fig. 5 an example of computed x_1 FFT-amplitude spectrum and the corresponding phase-space diagram there is presented.

Different patterns, reflecting ordered or disordered behaviors of the DL, depend on the amplitude and the frequency of the perturbing force e. The succession of the zones with different dynamics is similar to the experimental situation shown in Fig. 2.
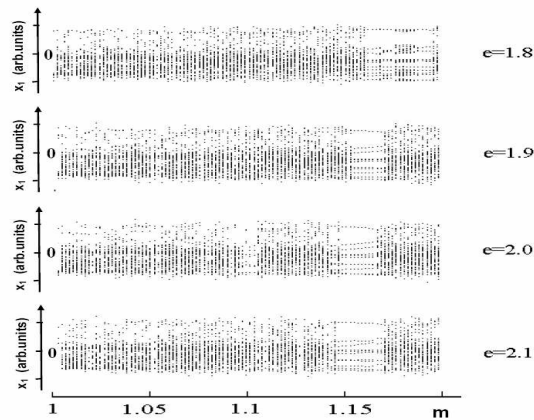
Fig. 4. Bifurcations diagrams for the computed values of x_1 versus control parameter m for different amplitudes e of the perturbing force. ($c = f = 1$, $g = 0.0796$).
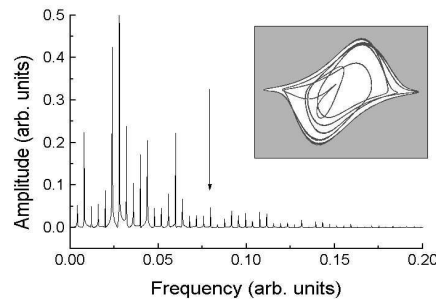

Fig. 5. A FFT amplitude spectrum and the corresponding phase–space diagram for the computed value of x_1. ($m = 1.17$, $e = 1..9$ – amplitude   and $g = 0.0796$ –   the frequency – indicated by arrow - of the perturbing force).

Also, the numerical model, like in the experiment reveals, in the frame of the chaos control, transitions from chaotic to periodic DL plasma system induced by the harmonic forcing.

4. Conclusions

Using fine and continue variation of the control parameter for DL it was possible to give a complete picture of the perturbed DL dynamics in the frequency (time) evolution.

The harmonic perturbation of a chaotic DL can induce transitions to ordered states or not (remaining chaotic). This fact depends on the parameters of the perturbation, which gives the possibility to control the chaotic states of this device in another way than by changing the dc bias supply. The numerical results of the model are in reasonable agreement with the experiment.

Acknowledgement

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