J. Plasma Fusion Res. SERIES, Vol. 3 (2000) 614–617

Flicker Noise Related to Electrical Double Layer Dynamics

SANDULOVICIU Mircea*, SCHRITTWIESER Roman[1], LOZNEANU Erzilia,
AVRAM Codrina, BALAN Petru and POHOATA Valentin
Department of Plasma Physics, "Al. I. Cuza" University, RO-6600 Iasi, Romania
[1]Institute for Ion Physics, University of Innsbruck, A-6020 Innsbruck, Austria

(Received: 18 January 2000 / Accepted: 4 April 2000)

Abstract

Transport of particles and energy by the effect of double layers, self-assembled at the edge of a confined plasma, towards a space charge configuration able to perform natural oscillations, reveals a new mechanism of anomalous transport of particles and energy in plasma devices. Based on these experimental results we suggest a new phenomenological basis for the explanation of flicker noise in fusion devices.

Keywords:
double layers, anomalous transport, instability stimulation.

1. Introduction

This paper presents experimental results on the non-linear behavior of a gaseous conductor (plasma) in which, under special conditions, complex space charge configurations are spontaneously created by self-organization. In contrast to fusion plasmas, where the confinement is determined by the external and internal magnetic fields, the complexities investigated here are self-confined by a spontaneously formed electrical double layer (DL). Like every physical system, such a self-confined space charge configuration tends to evolve into a steady state characterized by a local minimum of the free energy [1,2]. In the absence of external magnetic or electric fields, the steady state corresponds to a complexity bordered by a spherical DL. In this respect the observed phenomena can be considered as a phase transition since the spontaneous formation of such a complexity shows some similarities with the formation of droplets in liquids.

The experimental results suggest that the non-linearity of a plasma gives rise to a natural evolution during which self-organized complex space charge configurations are assembled in the system [3]. Their appearance and dynamics can explain some phenomena in different plasma devices that are not well understood up to now. Many of these theoretically unsolved problems are connected to the general acceptance of the so-called collision-less plasma concept [4].

*Corresponding author's e-mail: msandu@uaic.ro

2. Experimental Device and Results

The experiments have been performed at the DP-machine of the University of Innsbruck. In order to explain the results we consider recent investigations of similar phenomena in a plasma diode [1,2,5]. The Innsbruck DP-machine is presented in Fig. 1. It consists of a metal vessel, separated in two halves by a grid, filled with Ar in the pressure range of 10^{-4} mbar. The plasma was created in the target chamber by impact ionization due to electrons, originating from the heated filament W, accelerated to the metallic chamber wall by an appropriate discharge voltage. A tantalum disc electrode E, covered on its rear side with ceramic, was immersed in the plasma.

When a positive voltage V was applied to the electrode E and gradually increased and decreased, respec-

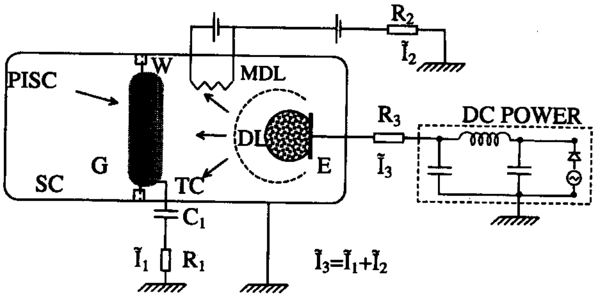

Fig. 1 Scheme of the experimental device. SC-source chamber, TC-target chamber, G-grid, DL-double layer, MDL-moving double layer, PISC-positive ion space charge, E-tantalum disc electrode, W-heated filament.

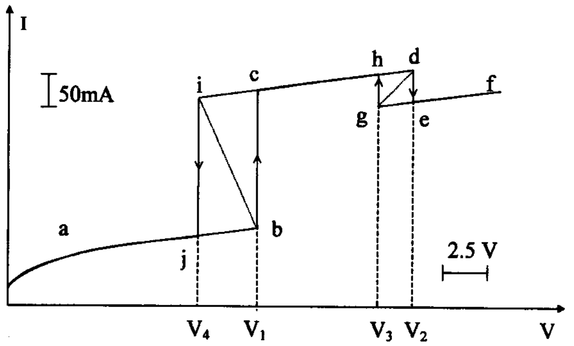

Fig. 2 Typical characteristic of an additional electrode in a DP machine.

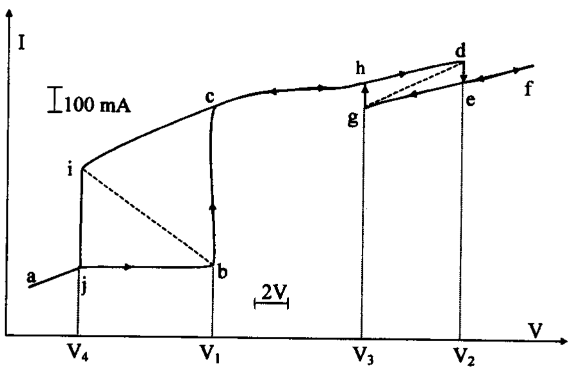

Fig. 3 Typical characteristic of an additional electrode in a collisional plasma diode.

tively, the current I to E showed abrupt variations for certain critical values of V. A typical characteristic is shown in Fig. 2. The presence of critical values of V, marked in Fig. 2 by subscripts, reveals that the status of the system depends sensitively on small random variations, controlled by "deterministic" chaos, ubiquitous in plasmas. Hysteresis phenomena, appearing in Fig. 2 when V is gradually decreased, prove that within certain voltage ranges the plasma shows bistability. In these voltage ranges, small variations of V lead to sudden transitions of the plasma into different conductive states. In the voltage range V_4-V_1 and V_3-V_2, the characteristic is S-shaped, respectively Z-shaped. Having a negative differential resistance the plasma is able to stimulate oscillations [5].

For explaining this behavior in a DP-machine we present, for comparison, an $I(V)$ characteristic of a plasma diode (Fig. 3) in which phenomena similar to those in the DP-machine were observed. We note that the static $I(V)$-characteristics of both plasmas show two abrupt variations of I. Both are also the onsets of instabilities.

The first instability appears for $V = V_1$ on a time scale corresponding to a frequency range of hundred Hz. This time scale is related to intermittent transitions, due to internal non-controllable fluctuations between an almost planar and an almost spherical space charge configuration that is usually called fireball [1].

The second instability appears for $V = V_2$ on a time scale corresponding to a frequency range of kHz and higher. Its appearance is related to the transition of the fireball to a steady state self-maintained by the proper dynamics of the DL. During this dynamics DLs are detached and reformed at the border of the fireball [1,2]. This effect produces intermittent limitations of I, which yields to the plasma conductor the behavior of a Z-shaped negative resistance. Consequently, the presence of a space charge configuration in the circuit, which is able to perform natural oscillations, transforms the system into a plasma oscillator [2,5,6]. In the absence of such a naturally oscillating system, the ac component of I reveals the presence of a typical 1/f flicker noise spectrum (Fig. 4a).

Measurements of the ac component of the currents through the resistors R_1, R_2 and R_3 (Fig. 1) prove that the ac current flowing from W toward E is an important part of the total ac current collected by E ($\cong$ 50%). The other part of the ac current flows from G to E through the capacitors of the DC power supply. We notice that after the appearance of the fireball, the dc discharge between W and E is maintained also without the discharge voltage, usually applied between W and the chamber walls, i.e., no plasma is created by diffusion from the walls into the center of the chamber. Under such conditions the DP-machine works as a usual plasma diode with a heated cathode. This proves that the fireball

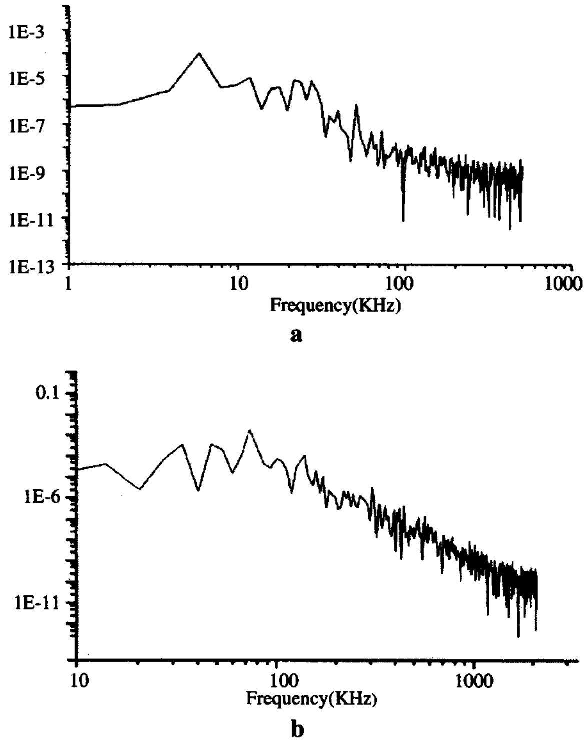

Fig. 4 Power spectrum obtained from a DP-machine (a) and from a collisional plasma diode (b).

formed in front of E is similar to the phenomena in a usual plasma diode.

3. Discussion

A brief analysis of the phenomena in the DP-machine proves the appearance of anomalous transport of particles and energy. This transport is caused by the effect of DLs after their detachment from the border of the fireball. The latter is formed by self-organization in front of the positively biased electrode E. The DLs are then shifted towards the space charge configuration around G, which is able to support natural oscillations. The necessary gradient of kinetic energy of electrons which leads to the formation of a DL around the fireball and starts its detachment is obtained for $V = V_2$. The self-organization scenario which explains the creation of a fireball and its dynamics, has already been described in detail elsewhere [1,2,6]. In the voltage range V_1–V_2 the fireball is in a stable state. For $V = V_2$ the fireball transforms into a steady state during which its self-confinement process is ensured by the proper dynamics of the DL. Coherent oscillations appear in the DP-machine due to the presence of a cloud of positive ions around the floating G (which becomes negatively charged). Such a cloud of positive ions is able to perform natural oscillations [7]. In our case we have observed such oscillations in the frequency range of 5 kHz with an amplitude of 600 V, which is higher than the dc voltage applied to E ($\cong$ 400 V).

In a system oscillations can be maintained when two conditions are satisfied [8]. Firstly, a system is needed able to perform natural oscillations. Secondly, a complex space charge configuration is necessary able to stimulate such oscillations. Obviously such a stimulation mechanism requires the transport of particles and energy from the stimulator to the system able to oscillate naturally. In our case this anomalous transport of particles and energy is performed by the effect of DLs. These DLs are able to store in their structure an amount of particles and electric field energy (originated from kinetic energy of electrons [1,9]) that is released after their disruption in the electric circuit and, consequently, also to the positive space charge formed around the negatively charged grid G.

The spectrum related to this stimulation mechanism shows sharp single or multiple peaks owing to the presence of resonances. Flicker noise appears in the DP-machine when G is positively biased so that no cloud of positive ions is created. Under such conditions the temporal evolution of the detachment of the DLs from the edge of the fireball (produced at medium time scales) is controlled by "deterministic chaos". The disruption of the DLs is due to the disappearance of the "multi space charge layer" configuration formed by accumulation of slow electrons that have lost their energy due to impact excitations of neutrals on different energy levels. This latter phenomenon is very probably proved by the presence of very short time scale phenomena (~500 MHz) also observed by us in the DP machine. The superposition of both phenomena on different time scales offers a possible explanation for the appearance of the 1/f spectrum.

4. Conclusions

The experimental results discussed in this paper support the idea of universality of turbulent anomalous transport of particles and energy in all kinds of plasma devices. They suggest that the physical processes at the origin of plasma non-linearity reveal a natural evolution into a critical state, identified as the final product of a scenario of self-organization [9]. This scenario of self-organization is rooted on collective effects produced by the spatial separation of the excitation and ionization cross section functions. Such a self-organization mechanism, driven by the presence of a local gradient of the kinetic energy of electrons, is able to explain generally the scale invariant phenomena in laboratory experiments and nature revealed by the presence of 1/f noise [10,11].

References

[1] M. Sanduloviciu *et al.*, Phys. Lett. A **208**, 136 (1995).

[2] M. Sanduloviciu *et al.*, Phys Lett. A **229**, 354 (1997).

[3] T. Sato, J. Korean Phys. Soc. **32**, S109 (1997).

[4] C. Avram *et al.*, J. Phys. D.: Appl. Phys. **32**, 2750 and **2758** (1999).

[5] E. Lozneanu *et al.*, J. Plasma and Fusion Res. SERIES **II**, 389 (1999).

[6] E. Lozneanu and M. Sanduloviciu, to be published.

[7] G. Popa and R. Schrittwieser, Phys. Plasmas **1**, 32 (1994).

[8] G. Emeleus, Adv. in Electronics & Electron Phys. vol. 29 Acad. Press, New York 1964 p.59.

[9] M. Sanduloviciu, Romanian Rep. in Phys., in print

[10] B.A. Carreras *et al.*, Phys. Plasmas **5**, 3632 (1998).

[11] M. Sanduloviciu *et al.*, Interrelation between Plasmas Experiments in Laboratory and Space (International Workshop, Kreuth, Germany, 1999).