NONLINEAR PHENOMENA IN PLASMA AS A CONSEQUENCE OF SELF-ORGANIZATION

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Abstract

Recent experiments performed on physical plasma revealed the possibility to establish a direct relationship between non-linearity and the creation of space charge configurations with behavior usually attributed to living beings. Such a "viable" self-organized complexity acts as the "vital" part of a plasma oscillator working with differential negative resistance and, in certain conditions, as the genuine cause of the so-called Turing instability.

1. Introduction

Physical plasma represents a system of many interacting particles that in thermal equilibrium, in a good approximation, is asymptotically stable [1]. Its strong non-linear behavior can be emphasized by matter and energy injection. This injection can be gradual or sudden. In the first case, plasma evidences intermittent order creation controlled by the external constraint, whereas in the second case the plasma relaxes, only due to internal causes, into an ordered complex structure [2].

2. Experimental results and discussions

Information concerning the physical processes involved in the non-linear behavior of a plasma in correlation with intermittent creation of order, but also in the destruction of order, can be obtained when energy and matter are continuously injected or extracted in (from) a diode like that shown in Fig. 1.

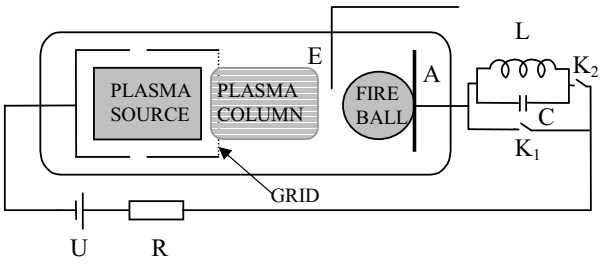

Fig. 1. Experimental device. The I(V) characteristic was plotted when K_1 is closed and K_2 opened.

Thus gradually increasing the voltage U of the external dc power supply directly connected to A, one observes that the plasma firstly adapts smoothly to the external constraint. In this phase the I(V) characteristic shows a positive differential resistance (branch $a \rightarrow b$ in Fig. 2). The plasma between the

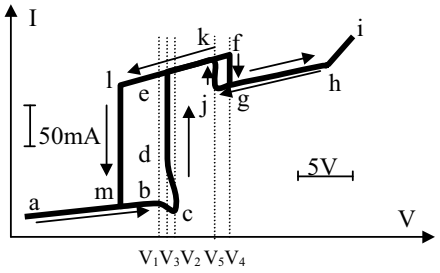

Fig. 2. Static I(V) characteristic of the plasma diode shown in Fig. 1. The branch h → i corresponds to the stimulated strong oscillations in a resonant system coupled to the device.

plasma **s**ource (PS) and the plate anode A relieves a first anomalous behavior if V, the self-adjusted voltage between the PS and A, reaches the value V_1. Beginning with V_1 the I(V) characteristic shows a **d**ifferential **n**egative **r**esistance (DNR) (branch b → c). Its appearance is related to the formation in front of A of a local net negative space charge that acts as a barrier for I. Such a barrier is formed by accumulation of that part of electrons that obtained, after acceleration towards A, energies for which the neutral excitation cross section function begins to increase. Losing the energy after neutrals' excitation, the electrons accumulate in a well-localized region in front of A determining I decrease. This local accumulation of electrons is a first phase by which an external constraint produces order in the plasma. Beginning from V_2, ionization processes appear in the plasma column, so that its internal resistance decreases. This is evidenced by the branch c → d in Fig. 2 so that a S shaped DNR can be observed in the I(V) static characteristic.

When U is further increased, V reaches a second critical value V_3 for which I increases abruptly. Such a sudden I increase proves the spontaneous appearance of a new source of charged particles [1,3,4]. The physical process able to explain this behavior [1] is the formation in front of A of an electrical **d**ouble **l**ayer (DL) that surrounds the fireball shown in Fig. 3. We notice that the fireball appearance takes place spontaneously because its generation corresponds to an internal process during of which an ordered structure characterized by local minimal value of the free energy is self-assembled. Its "birth" is accompanied by entropy "expulsion" [2].

Fig. 3. Photograph of the fireball

When, under special conditions as those described in [5], fireballs are formed at the one-dimensional anode, their reciprocal positions are determined by the repulsive electrostatic forces acting between them [6]. Therefore changing the anode voltage so that the fireball replicates in the form of a striated positive column the same repulsive electrostatic forces determine the observed current filamentation. The presence of the electrostatic forces was experimentally proved using instead of linear anode, similar to that described in [5], two point anodes placed at such a distance that the effect of the repulsive forces can be direct observed (Fig. 4).

The most spectacular phenomenon appears in the plasma diode in the form of temporal ordered structures. These appear when U is further increased so that V = V_4 and I suddenly decreases (branch f→g). The temporal ordered structure is emphasized in the dynamical I(V) characteristic shown in Fig. 5 (obtained when U is swept with a frequency closed to the I modulation). Its appearance makes possible to explain the unsolved challenging problem concerning the relationship between spatial and temporal order.

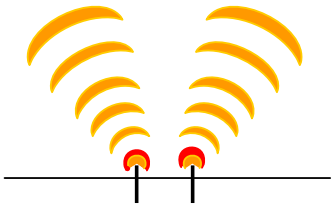

Fig. 4. Schematic representation of two striated positive columns between which electrostatic repulsive forces act. The used experimental device is similar to that described in [5].

Thus, investigating the behavior of the fireball formed in front of A, we experimentally proved the presence of a self-sustained dynamics during of which its viability is assured by a rhythmic exchange of matter and energy between the fireball and the surrounding plasma [1,3,4].

The presence of a self-organized structure able to sustain, by internal processes, its viability reveals also the genuine origin of the DNR usually evidenced in the static I(V) characteristic. In this I(V) characteristic it really corresponds to the averaged I intensity measured under conditions that the above mentioned modulation of I, with a "negative" amplitude, is present. This is an important experimental result proving that viable complex structures can act as "vital" part of oscillators. The stimulation of oscillations in an external LC resonant circuit was experimentally proved using the device shown in Fig. 1. Strong oscillations appear in the LC circuit after its connection to the plasma diode. Returning to the static I(V) characteristic obtained when U is decreased, we observe the presence of hysteresis phenomena. Such phenomena are essential characteristics of systems resulting after self-organization [7]. Their presence proves the ability of the self-organized complex structure to memorize, after "birth", its past history. With other words, such a complexity becomes able to maintain its ordered (self-organized) structure also under conditions that the matter and energy transferred to the system become smaller than those required for its genesis.

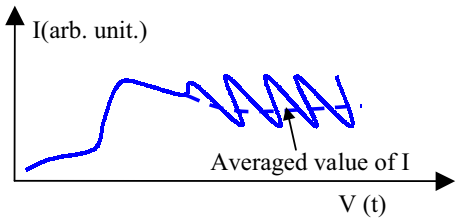

Fig. 5. Dynamic I(V) characteristic proving the appearance of a N shaped DNR in the averaged value of I.

Order creation by sudden injection of energy and matter in a system initially in thermodynamic equilibrium, can be observed also in our plasma diode. In this case the

starting moment of the self-organization process is an electrical spark between an additional electrode E and A (Fig. 1). Under such conditions in the impact point of the spark on the A surface, a high temperature plasma is produced. Owing to the differences between the thermal diffusivities of electrons and positive ions, the electrons leave this region so that a well-localized positive nucleus is generated. This nucleus acts as a gas anode initiating a relaxation phenomenon that comprises a succession of key process similar to that produced in front of A when its voltage is gradually increased [4].

3. Conclusions

Two branches of the static I(V) characteristic present special interest for explaining the mechanism at the origin of DNR. The first one is the branch $b \to c \to d \to e \to f$ that corresponds to the S shaped DNR. Its origin is related to the intermittent formation and disruption of a self-organized space charge configuration (the fireball) in front of A. The second one is the branch $f \to g \to h \to i$ that evidences the presence of a N shaped DNR. At the origin of this DNR is the presence of a self-organized complex structure able to self-sustain, by internal processes, a rhythmic exchange of matter and energy with the surrounding.

Both DNRs are able to stimulate oscillations in a suitable connected resonant system. The DNR presence in a plasma oscillator [8] but, very probable, also in a Gunn oscillator [9], both systems being in an unanimated world, suggests a possible relationship between the phenomenology at the origin of the vital part of an oscillator working with DNR and those assuring the viability of natural cell structures.

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