

EXPERIMENTAL BASIS OF A COMMON PHYSICAL MECHANISM FOR THE CONCENTRIC AND NON-CONCENTRIC MULTIPLE DOUBLE LAYERS IN PLASMA*

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The concentric and non-concentric multiple double layers were intensively investigated in plasma in the last years because of its potential applications in optoelectronics and nano-technologies. Here we report on experimental results on multiple double layers, concentric as well as non-concentric, that emphasize that a common physical mechanism can be at the origin of the appearance and dynamics of both types of structures. Thus, our results prove that the electron-neutral impact excitations and ionizations reactions are at the basis of its emergence and dynamics in plasma. Also, in physical conditions far from the structures equilibrium, both types of multiple double layers evolve towards the chaos after a similar scenario.

Key words: multiple double layers, excitation, ionization, instability, chaos.

INTRODUCTION

By applying a positive potential on an electrode immersed in plasma, a complex space charge structure in form of an intense luminous spherical body appear in front of it, known as anode glow [1] or fireball [2]. Experimental investigations revealed that such a structure consists of a positive core (an ion-enriched plasma) surrounded by a nearly spherical double layer [2–5]. The potential drop across the double layer is almost equal with the ionization potential of the used gas atoms.

Under certain experimental conditions, a more complex structure in form of two or more subsequent double layers was observed [6–11], called multiple double layers. It appears as several bright and concentric plasma shells attached to the anode of a glow discharge or to a positively biased electrode immersed in plasma. The successive double layers are precisely located at the abrupt changes of luminosity between two adjacent plasma shells. Recently [12], this type of multiple double layers was called concentric multiple double layers.

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If the electrode is large with respect to the characteristic length of the plasma, or if it is strongly asymmetric (with a mainly one-dimensional geometry), the multiple double layers structure appears non-concentrically, as a network of intense luminous plasma spots, located near each others, almost equally distributed on the electrode surface [13–17]. This kind of structure was called non-concentric multiple double layers [18].

Here we present experimental results related to the appearance and dynamics of both types of multiple double layers, which indicate the existence of a common physical mechanism at their origin.

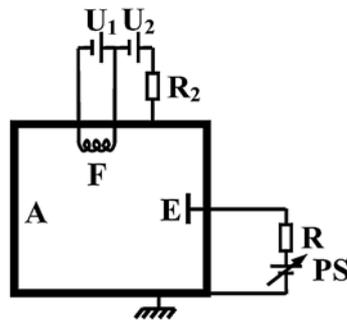


Fig. 1 – Experimental setup.

EXPERIMENTAL RESULTS AND DISCUSSION

The experiments were performed in a plasma diode, schematically represented in Fig. 1. Plasma is created by an electrical discharge between the hot filament (marked by F in Fig. 1) as cathode and the grounded tube (made from stainless steel) as anode. The plasma was pulled away from equilibrium by gradually increasing the voltage applied to different types of electrodes (generally marked by E in Fig. 1), under the following experimental conditions: argon pressure $p = 5 \times 10^{-3}$ mbar, plasma density $n_{pl} = 10^{10}$ cm $^{-3}$.

The first electrode that we introduced in plasma was a tantalum disk electrode with 1 cm diameter. Fig. 2 shows the static current-voltage characteristic

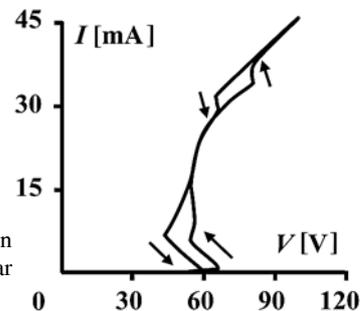


Fig. 2 – Static current-voltage characteristic obtained in the conditions when two concentric plasma shells appear in front of a small electrode.

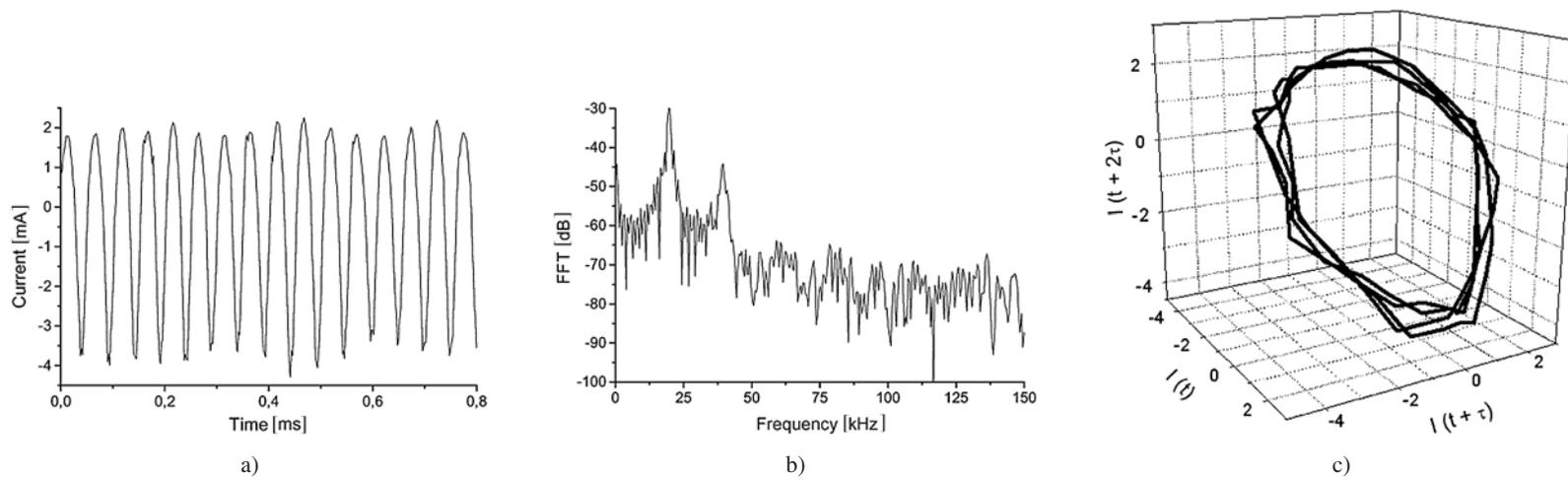


Fig. 3 – The ac component of the current (a), their FFT's (b) and the reconstructed state space of the plasma system dynamics (c) when a simple double layer appears in front of the electrode.

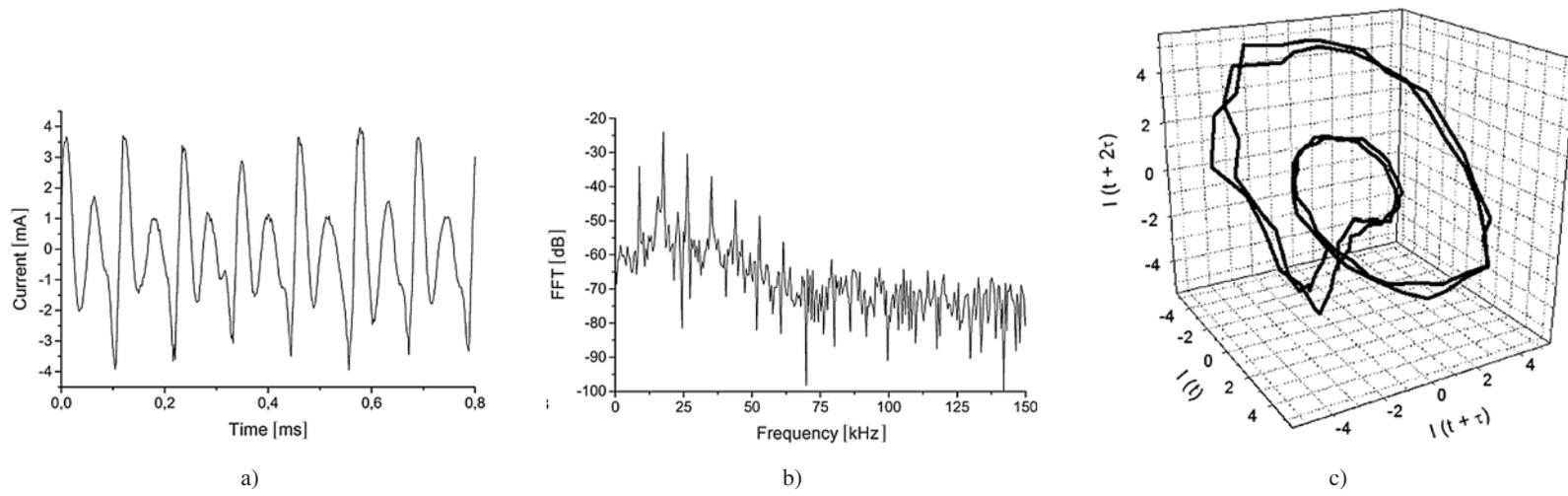
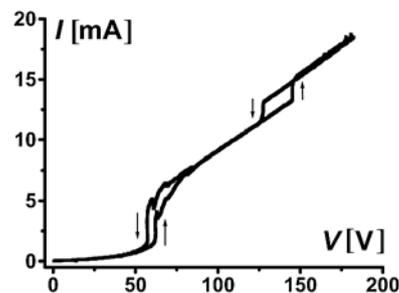


Fig. 4 – The ac component of the current (a), their FFT's (b) and the reconstructed state space of the plasma system dynamics (c) when two concentric double layers appear in front of the electrode.

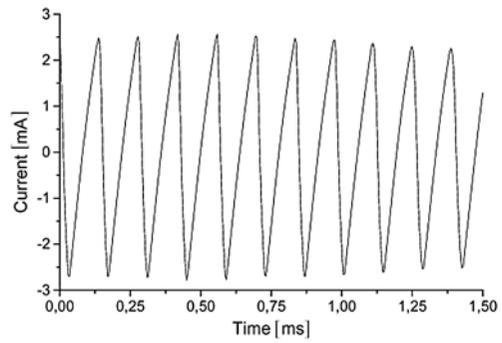
of the electrode, obtained by gradually increasing and subsequently decreasing the potential on the electrode. In this characteristic two current jumps associated with hysteresis effect can be observed. After the first jump, a quasi-spherical luminous structure appears in front of the electrode. Simultaneously, the current becomes time dependent, the oscillations being shown in Fig. 3a and their FFT's in Fig. 3b. After the second jump of the current a second luminous sheet appears, surrounding the first one (concentric multiple double layers). The current oscillations become more complex (see the time series in Fig. 4a and their FFT's in Fig. 4b). These emphasize a doubling period bifurcation, best illustrated in the reconstructed state space of the plasma system dynamics (by time delay method [19]) in Fig. 3c and 4c.

Fig. 5 – Static current-voltage characteristic obtained in the conditions when two plasma spots appear on the surface of a large electrode.

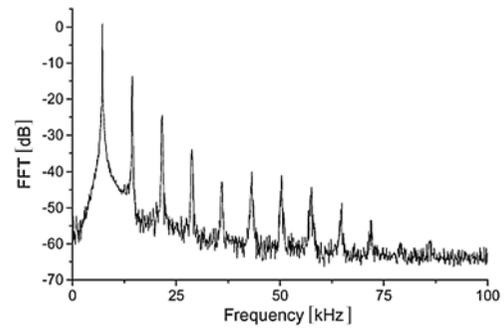


The second electrode that we used was a tantalum disk with 3 cm diameter. Fig. 5 shows the static current-voltage characteristic of this electrode. One can observe again the appearance of two jumps of the current with hysteresis. After the first jump of the current, a luminous plasma spot with about 5–6 mm diameter appears at a certain point on the electrode surface. Simultaneously, the current becomes time dependent (see the time series of the ac component of the current in Fig. 6a and their FFT's in Fig. 6b). By further increasing the potential on the electrode, the current makes the second jump, after which a second plasma spot appears on the electrode near the first one (non-concentric multiple double layers). The current oscillations shape is changing (see the time series of the ac component of the current in Fig. 7a and their FFT's in Fig. 7b). The period doubling bifurcation is again present (see Fig. 6c and 7c).

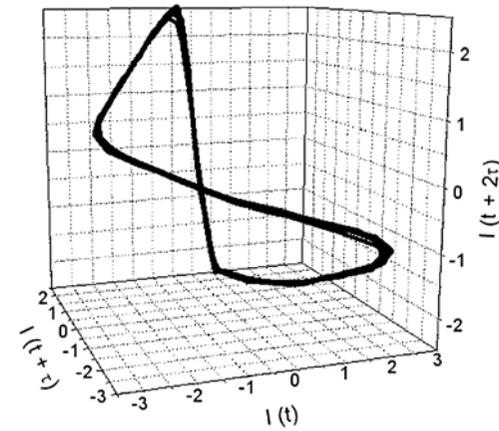
These results suggest the existence of a common physical mechanism at the origin of the appearance and dynamics of both types of multiple double layers. This assertion is also sustained by other experimental observations. For example, the number of luminous shells, as well as of plasma spots, depends on the discharge current in the same way. Thus, larger discharge currents decrease the number of structures [8, 12, 18]. In this common physical mechanism the excitation and ionization electron-neutral impact play a key role. These reactions ensure the positive and negative charges needed for the existence of the structure.



a)

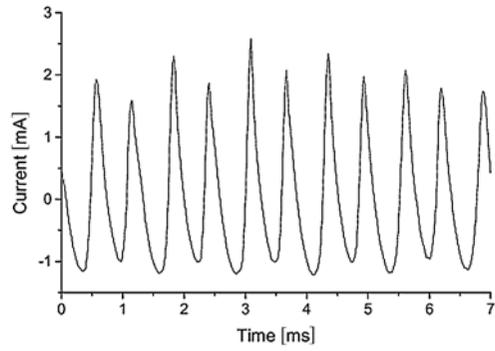


b)

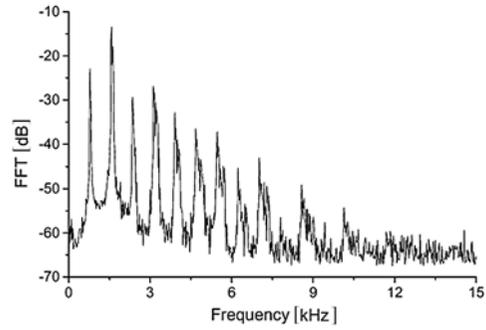


c)

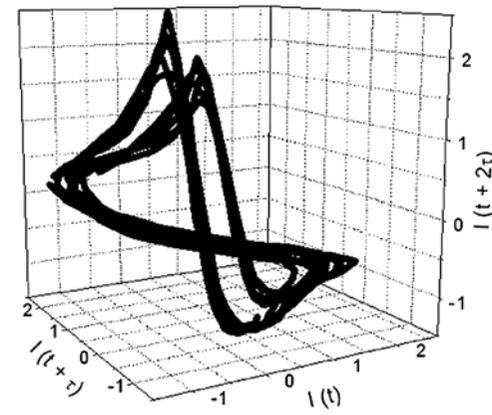
Fig. 6 – The ac component of the current (a), their FFT's (b) and the reconstructed state space of the plasma system dynamics (c) when a simple plasma spot appears on the electrode.



a)



b)



c)

Fig. 7 – The ac component of the current (a), their FFT's (b) and the reconstructed state space of the plasma system dynamics (c) when two plasma spots appear on the electrode.

CONCLUSION

Experimental results are presented that emphasize striking similarities between the generation and dynamics of concentric and non-concentric multiple double layers. A common physical mechanism at the origin of these two phenomena is suggested, in which the excitation and ionization electron-neutral impacts play the most important role.

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