Generation and Dynamics of Multiple Double Layers in Plasma

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1. Introduction

Double layers (DLs) are nonlinear potential structures in plasma consisting of two adjacent layers of positive and negative space charges, in which the existing potential jump creates an electric field. One common way to obtain a DL structure is to positively bias an electrode immersed in a plasma in equilibrium. In this case, a complex space charge structure (CSCS) in form of a quasi-spherical luminous body attached to the electrode appears. Such a CSCS consists of a positive core (ion-enriched plasma) confined by a nearly spherical DL [1,2]. The potential drop across DL is almost equal to the ionization potential of the background gas atoms.

Under certain experimental conditions, a more complex structure in form of two or more subsequent DLs was observed [3-5], called a multiple double layer (MDL). 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 DLs are precisely located at the abrupt changes of luminosity between two adjacent plasma shells. The axial profile of the plasma potential has a stair step shape, with each potential drop being close to the ionization potential of the gas atoms [3,5]. This kind of structure was recently called concentric multiple double layer [6].

If the electrode is large with respect to the characteristic length of the plasma, or if it is strongly asymmetric (e.g. with a mainly one-dimensional geometry), the multiple double layer structure appears non-concentrically, as a network of plasma spots located near each other, almost equally distributed on the electrode surface [7-9]. The MDL obtained in such a way was called non-concentric multiple double layer [10].

Here we present experimental results that show striking similarities between the generation and dynamics of concentric and non-concentric MDLs. Common nonlinear phenomena appear in the static current-voltage characteristic of the electrodes, as well as in the dynamic behaviour of the two types of MDL. The experimental results lead to the conclusion that a common physical mechanism exists at the origin of both types of MDL.

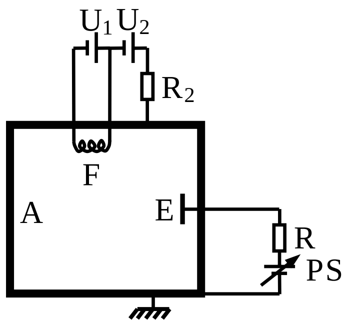


Fig. 1: Experimental setup

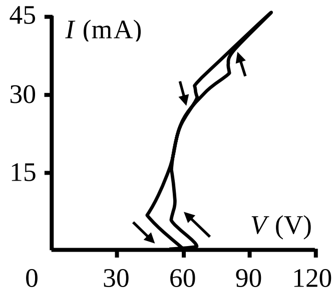


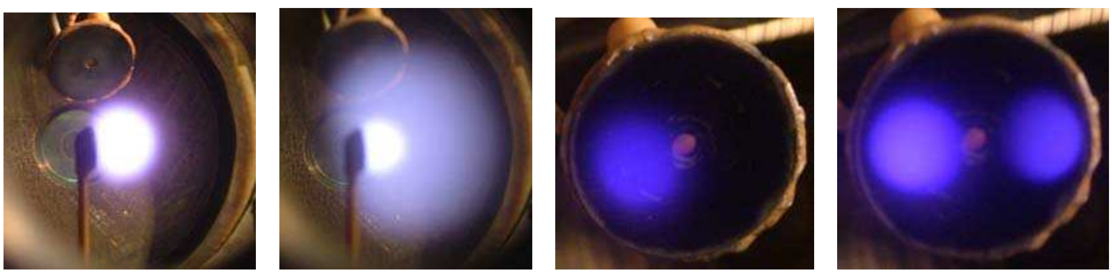
Fig. 2: Static current-voltage characteristic obtained in the conditions when two concentric plasma shells appear in front of a small electrode

2. 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 as anode. The plasma was pulled away from equilibrium by gradually increasing the voltage applied to different types of electrode (generally marked by E in Fig. 1), under the following experimental conditions: argon pressure $p = 5{\cdot}10^{-3}$ mbar, plasma density $n_{pl} \cong 10^{9}$-10^{10} cm^{-3}.

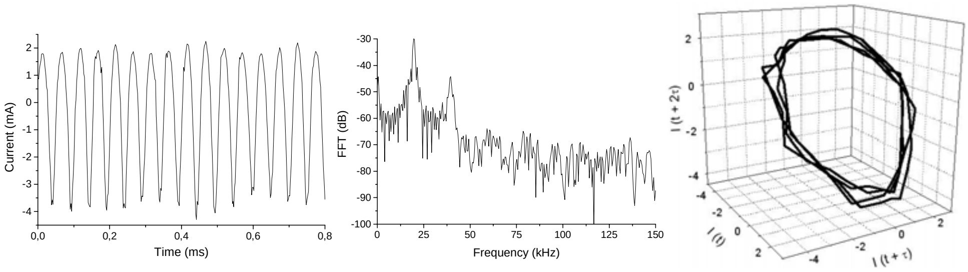
The first electrode introduced into the plasma was a tantalum disk electrode with 1 cm diameter. Fig. 2 shows the static current-voltage characteristic of the electrode, obtained by gradually increasing and subsequently decreasing the potential on the electrode. In this characteristic, two jumps of the current associated with hysteresis can be observed. After the first jump, a quasi-spherical CSCS appears in front of the electrode (see the photo in Fig. 3a). Simultaneously, the current becomes time dependent (see the time series of the ac component of the current in Fig. 4a and their FFT's in Fig. 4b). After the second jump of the current a second luminous sheet appears, surrounding the first one (see the photo in Fig. 3b). The current oscillations become more complex (see the time series of the ac component of the current in Fig. 5a and their FFT's in Fig. 5b), emphasizing a doubling period bifurcation, best illustrated in the reconstructed state space of the plasma system dynamics (by time delay method [11]) in Figs. 4c and 5c.

The second electrode used was a tantalum disk electrode with 3 cm diameter. Fig. 6 shows the static current-voltage characteristic of this electrode. Again the appearance of two current jumps with hysteresis can be observed. After the first jump, a luminous plasma



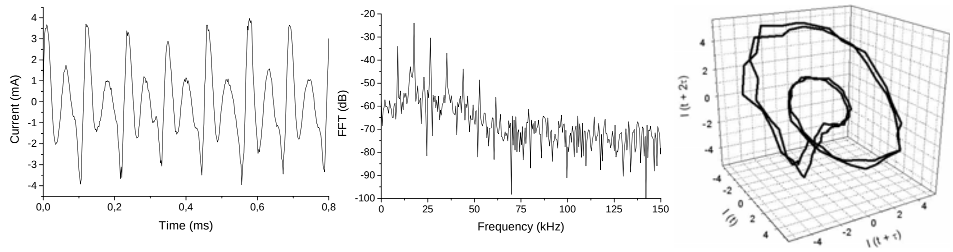
(a) (b) (c) (d)

Fig. 3: Photos of the complex luminous structure obtained on small (a and b) and large (c and d) electrodes.



(a) (b) (c)

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 a simple double layer appears in front of a small electrode.



(a) (b) (c)

Fig. 5: 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 a small electrode.

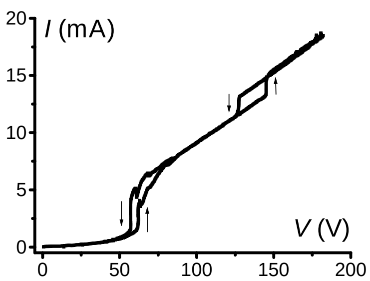
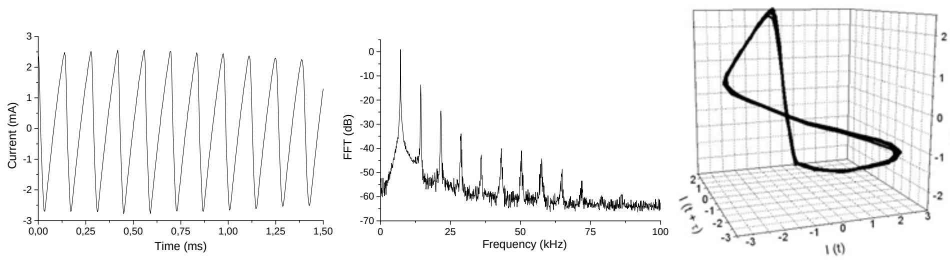


Fig. 6: Static current-voltage characteristic obtained in the conditions when two plasma spots appear on the surface of a large electrode.

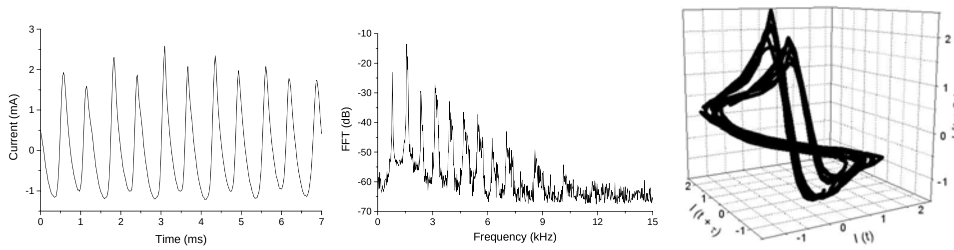
spot with about 5-6 mm diameter appears at a certain point of the electrode (see the photo in Fig. 3c). The current becomes time dependent (see the time series of the ac component of the current in Fig. 7a and their FFT's in Fig. 7b). By a further increase of the electrode voltage, the current makes a second jump, after which a second plasma spot appears on the electrode, near the first one (see the photo in Fig. 3d). The current oscillations change their shape (see the time series of the ac component of the current in Fig. 8a and their FFT's in Fig. 8b), the period doubling bifurcation being again present (Figs. 7c and 8c).

There are more experimental results common to concentric and non-concentric MDLs. For example, the number of luminous shells as well as plasma spots, respectively, depends on the discharge current, i.e. on the plasma density, and the voltage applied to the electrode in the same way: in both cases larger discharge currents decrease the number of structures, whereas the voltage applied to the electrode plays the opposite role [3,6,10]. These results suggest that there is a common physical mechanism at the origin of both concentric and non-concentric MDLs. In this mechanism, electron-neutral impact excitations and ionizations play a key role [5,12].



(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 a single plasma spot appears on a large electrode



(a) (b) (c)

Fig. 8: 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 a large electrode

Conclusion

Experimental results are presented emphasizing striking similarities between the generation and dynamics of concentric and non-concentric multiple double layers in plasma. The results suggest a common physical mechanism at the origin of both phenomena.

Reference

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