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PHYSICAL PROCESSES AT THE ORIGIN OF THE APPEARANCE AND DYNAMICS OF MULTIPLE DOUBLE LAYERS[1]

L. M. Ivan[2]*, G. Amarandei *†, M. Aflori *, M. Mihai-Plugaru *, D. G. Dimitriu *†, C. Ionita †, R. W. Schrittwieser[3]†

* *Department of Plasma Physics, "Al. I. Cuza" University, 11 Carol I Blvd., RO-700506 Iasi, Romania*

† *Institute for Ion Physics, Leopold-Franzens University, Technikerstr. 25, A-6020 Innsbruck, Austria*

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Concentric and non-concentric multiple double layers were investigated in a double plasma machine, under various experimental conditions. The obtained results prove that a common mechanism is at the origin of the appearance and dynamics of both types of multiple double layers. In this mechanism, electron-neutral impact excitations and ionizations play an important role.

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1 Introduction

Double layers (DLs) [1] in plasma are nonlinear potential structures consisting of two adjacent layers of positive and negative space charges, respectively. Between these layers a potential jump exists, creating an electric field. A common way to obtain a DL structure is to positively bias an electrode immersed in a plasma being in equilibrium. In this case, a complex space charge structure (CSCS) in form of a quasi-spherical luminous body attached to the electrode is obtained. Experimental investigations revealed that such a CSCS consists of a positive "nucleus" (an ion-rich plasma) surrounded by a nearly spherical DL [2]. The potential drop across the DL is almost equal to the ionization potential of the background gas atoms.

Under certain experimental conditions (plasma density, gas nature and pressure, electron temperature) a more complex structure in form of two or more subsequent DLs was observed [3–7], which was called multiple double layer (MDL). It appears as several bright and concentric plasma shells attached to the electrode. The successive DLs are precisely located at the abrupt changes of luminosity between two adjacent plasma shells. Probe measurements emphasized that the axial

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[2]E-mail address: mihaela.ivan@plasma.uaic.ro

[3]E-mail address: roman.schrittwieser@uibk.ac.at

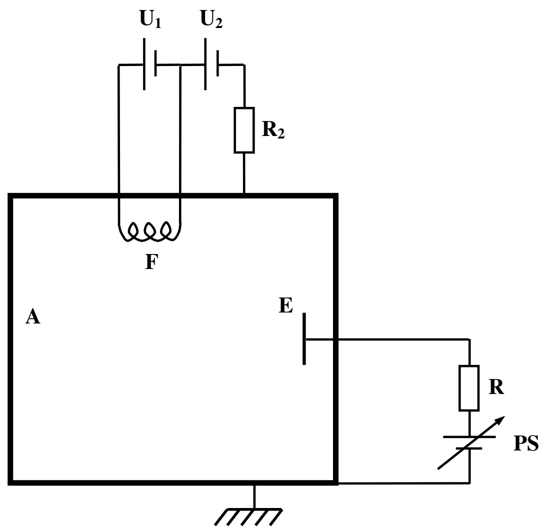


Fig. 1. Schematic of the experimental setup (F - filament, E - electrode, A - anode, U_1 - power supply for heating the filament, U_2 - power supply for discharge, PS - power supply for electrode bias, R - load resistor in the electrode circuit, R_2 - load resistor in the discharge circuit).

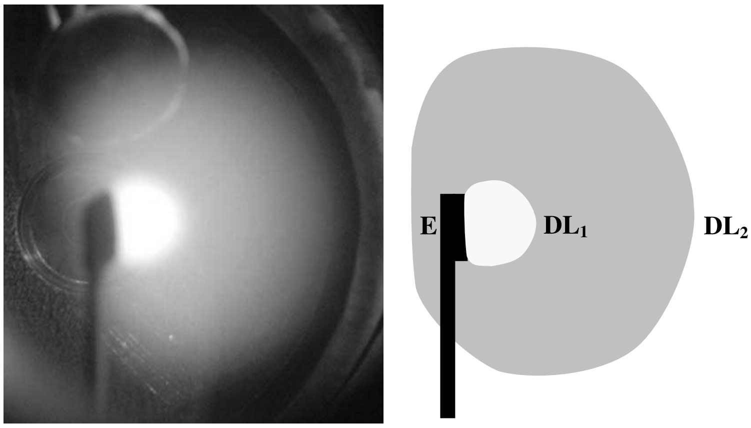
profile of the plasma potential has a stair steps shape, with potential jumps close to the ionization potential of the used gas [4, 7]. The static current-voltage *I-V* characteristic of the electrode reveals that each of the DLs appears simultaneously with a current jump [7]. Experimental results clarify the essential role of excitation and ionization electron-neutral collisions for the generation and dynamics of MDL structures [7].

However, if the electrode is large or asymmetric (with one dimension larger than the others), the MDL structure appears non-concentrically, as a network of plasma spheres, near each other, almost equally distributed on the electrode surface [8–12]. Each of the plasma spots is a CSCS as described above.

Here we present experimental results on non-concentric MDLs, which prove that both types of MDLs (concentric and non-concentric) are similar structures, the same physical mechanism being implied in their generation. The plasma spheres which form a non-concentric MDL, appear successively with the increase of the potential on the electrode, simultaneously with current jumps in the static current-voltage characteristic of the electrode, associated with hysteresis effects.

2 Experimental results

The experiments were performed in the double plasma (DP) machine of the University of Innsbruck. The DP-machine consists of a large cylindrical non-magnetic stainless steel tube (90 cm long and 45 cm diameter), evacuated by a roughing pump and a diffusion pump to a base pres-



(a) **(b)**

Fig. 2. Concentric multiple double layers structure obtained on a small disk electrode (photo (a) and schematic draw (b), E - electrode, DL - double layer).

sure of about 10^{-4} Pa. A metallic grid separates the tube into two chambers: the source chamber and the target chamber. In our experiments we used only the target chamber, schematically represented in the Fig. 1. By filling the discharge chamber with argon to a pressure in the range of a few Pa, 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 (marked by A in Fig. 1). Because of the small dimensions, the filament collects negligible part of the ions, most of them are diffusing towards the center of the tube. The positive space charge attracts many electrons into this region. In this way, a plasma with a high degree of ionization appears. To reduce plasma losses, on the walls rows of permanent magnets of alternate polarity ($B \simeq 0.1$ T on the surface) are mounted. The plasma was pulled away from equilibrium by gradually increasing the voltage applied on different types of electrodes (generally marked by E in Fig. 1), under the following experimental conditions: argon pressure p = 5 Pa, plasma density $n = 10^{16}$ m^{-3}.

First, a tantalum disk electrode of 8 mm diameter, was used. At a certain value of the potential on the electrode, a CSCS appears in front of it. By further increasing the electrode potential, successive DL structures appear, surrounding each other. In Fig. 2 we can observe two such DL structures, obtained for $V_E \simeq 70$ V on the electrode. The axial profile of the plasma potential in front of the electrode has a stair steps shape, with potential jumps close to the ionization potential of argon [7]. The size of the structure and the number of plasma shells can be controlled by means of both, the electrode potential and the discharge current. Thus, larger potentials on the electrode increase the number of the plasma shells, while the increase of the discharge current plays the opposite role.

The second electrode used was a tantalum disk electrode, 3 cm in diameter. In this case, at a critical value of the potential on the electrode, a first luminous spot appears on a certain point of the electrode where the current is highest because of local reasons (for example the presence of

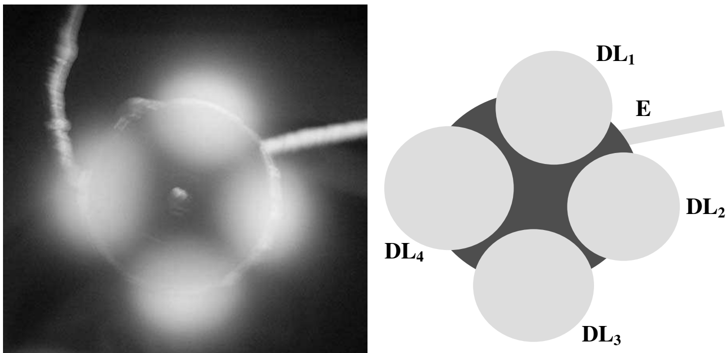


Fig. 3. Non-concentric multiple double layers structure obtained on a large disk electrode (photo (a) and schematic draw (b), E - electrode, DL - double layer).

protuberances on the electrode surface, or local gas emission). By further increasing the potential on the electrode more luminous spots appear on it, forming a non-concentric MDL structure. Fig. 3 shows an example, obtained at an electrode potential of $V_E \simeq 100$ V. Each of the spots appears simultaneously with a current jump in the static current-voltage $I-V$ characteristic (see Fig. 4 where the appearance of two spots was recorded simultaneously with two jumps of the current), associated with hysteresis effects. The size and the number of spots can be controlled in the same way as in the case of a concentric MDL, by varying the electrode potential and the discharge current.

The last electrode used was a tantalum ring electrode, 4 cm in diameter. The obtained luminous pattern is similar to that of the second case, but with a spatial distribution of spots imposed by the geometry of the electrode (see Fig. 5, obtained for an electrode potential of $V_E \simeq 100$ V). Each of the spots appears also simultaneously with a current jump in the static current-voltage characteristic. A similar structure of spots was obtained by using a rectangular electrode [13].

3 Discussion

The experimental results show many similarities between non-concentric and concentric MDLs. Thus, both types of MDLs have a similar structure, with an electrical DL surrounding a positive ”nucleus”. Each of the DL structures appears at a certain value of the potential on the electrode with respect to the plasma potential, simultaneously with a current jump in the static current-voltage of the electrode, associated with hysteresis effects. This proves that the same elementary processes are involved, namely electron impact excitations and ionizations of neutrals. These processes determine the appearance of negative and positive space charges, respectively, spatially well separated because of the dependence of the respective cross sections on the kinetic electron energies, which varies along the structure according to the axial profile of the plasma potential. When the potential drop between opposite space charges attains the ionization poten-

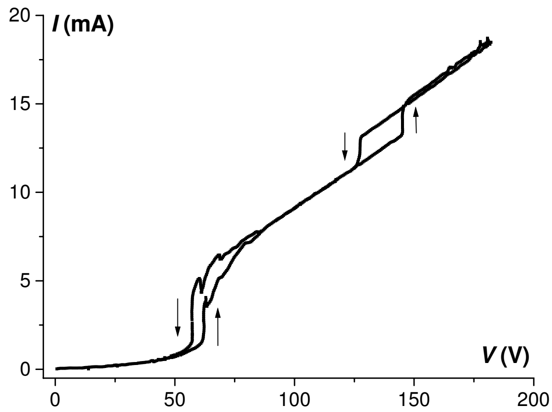


Fig. 4. Static current-voltage characteristic of the electrode obtained in the conditions where two plasma spots appear.

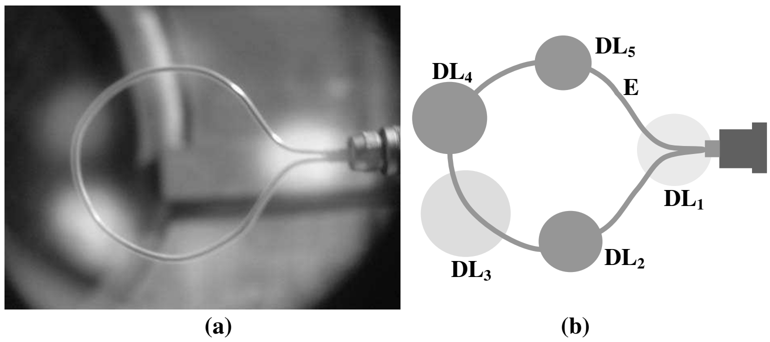


Fig. 5. Non-concentric multiple double layers structure obtained on a ring electrode (photo (a) and schematic draw (b), E - electrode, DL - double layer).

tial of the gas, each of the electrons that pass through the structure reaches enough energy to cause an electron-neutral impact ionization. In this way, an amplification of the electron current is obtained, recorded as one current jump in the static current-voltage characteristic of the electrode. If the experimental conditions allow (gas pressure, plasma density, electron temperature), by increasing the potential on the electrode we can create the necessary conditions for the appearance of a new DL structure, so a MDL structure emerges. Their appearance, i.e. concentric or non-concentric, respectively, depends on the geometry of the experiment, mainly on the dimensions of the electrode with respect to the characteristic lengths of the plasma. The current jump is associated with hysteresis effect, which proves the capability of each of the structures to maintain its existence under conditions less favorable than those required for their appearance.

This is characteristic for many nonlinear systems. Finally, we emphasize that the size and the number of the DL structures can be controlled in the same way in both cases (concentric and non-concentric MDLs, respectively).

4 Conclusion

Experimental results on the generation of concentric and non-concentric multiple double layers were presented. These results prove that a common physical mechanism is at the origin of the creation of both types of MDL. In this mechanism, the electron-neutral impact excitations and ionizations play the most important role.

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