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EXPERIMENTAL CONTROL OF THE GENERATION AND DYNAMICS OF A COMPLEX SPACE CHARGE STRUCTURE IN A DOUBLE PLASMA MACHINE[1]

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An additional electrode was used to control the appearance and dynamics of a complex space charge structure (CSCS) in plasma. The potential threshold of the CSCS appearance, as well as the amplitude and the frequency of its oscillations, strongly depends on the negative bias of this electrode with respect to the plasma potential.

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1 Introduction

It is well-known that a double plasma (DP) machine is a very favorable device for the study of potential structures, such as space charge sheaths, double layers (DLs), multiple double layers (MDLs), solitons, etc. [1–10]. However, these potential structures are very often unstable and excite different kinds of waves and instabilities. For a certain range of background pressure and plasma density, we have obtained a very stable complex space charge structure (CSCS) by applying a positive potential to a disk electrode immersed into a DP machine plasma. This CSCS appears as a quasi-spherical intense luminous body, attached to the electrode. It was also named anode glow, fireball or ball of fire. Emissive probe measurements showed that this CSCS consists of a positive nucleus (ion-rich plasma) confined by an electrical DL [11]. The stability of this CSCS was controlled by using a supplementary ring electrode, surrounding the disk electrode. By negatively biasing the ring electrode with respect to the disk electrode, the appearance and the dynamics of the CSCS can be controlled. Here, experimental results on these mechanisms are presented.

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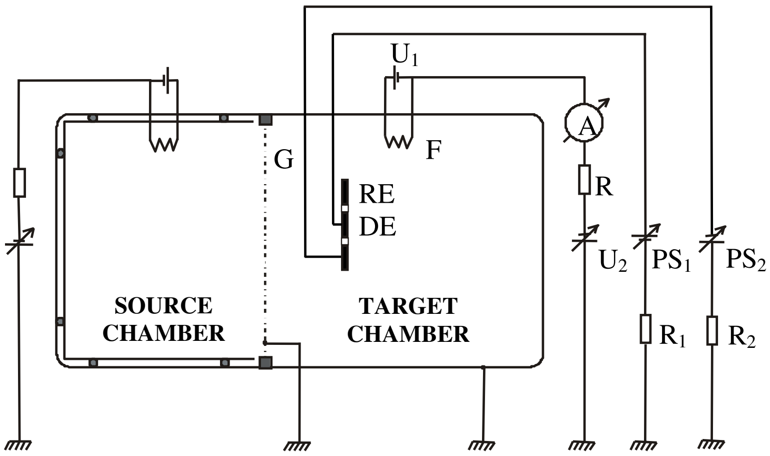

Fig. 1. Schematic of the University of Innsbruck DP machine (F - filament, G - grid, DE - disk electrode, RE - ring electrode, U_1 - power supply for heating the filament, U_2 - power supply for the discharge, PS_1 - power supply for DE bias, PS_2 - power supply for RE bias). The source chamber was not used in our experiments.

2 Experimental results and discussion

The experiments were performed in the double plasma (DP) machine of the University of Innsbruck, schematically represented in Fig. 1. The DP-machine consists of a large cylindrical non-magnetic stainless steel tube (90 cm long and 45 cm diameter), evacuated by a pre-vacuum pump and a diffusion pump to a base pressure of about 10^{-4} Pa. A metallic grid (marked by G in Fig. 1) separates the tube into two chambers: the source chamber (left-hand side of the tube in Fig. 1) and the target chamber (right-hand side of the tube in Fig. 1). By filling the DP-machine with argon to a pressure in the range of a few Pa, in each of the chambers plasma is created by an electrical discharge (about 100 V discharge voltage) between a hot filament (marked by F in Fig. 1) as cathode and the grounded tube as anode. Because of the small dimensions, the filaments collect negligible part of the ions, whereas 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, rows of permanent magnets of alternate polarity ($B \simeq 0.1$ T on the surface) are mounted on the walls.

In our experiments we used only the target chamber of the Innsbruck DP-machine. The plasma created in the target chamber was pulled away from equilibrium by gradually increasing the voltage applied on a tantalum disk electrode (marked by DE in Fig. 1), with 1 cm in diameter. A ring electrode (RE in Fig. 1) made also from tantalum, with 3 cm outer diameter and about 1 cm inner diameter, surrounded DE. On DE an increasing positive potential was applied from a dc power supply, while on RE a negative potential was applied with respect to the potential of the DE. The ballast resistors were 500 Ω in the DE circuit and 1 kΩ in the RE circuit. The background argon pressure was p = 0.5 Pa and the plasma density $n = 10^{15}$ m^{-3}. The static

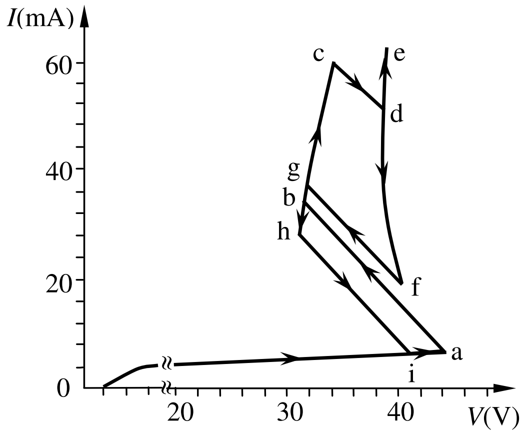

Fig. 2. Static current-voltage characteristic of the disk electrode DE.

current-voltage characteristic of DE, as well as the ac components of the electrode current and the FFT's of them were recorded with a computer-controlled digital oscilloscope.

Fig. 2 shows the static current-voltage (*I-V*) characteristic of the electrode DE, obtained by gradually increasing and subsequently decreasing the voltage on it. The ring electrode was kept at floating potential. When the voltage *V* is increased until the critical value corresponding to point **a** in the static characteristic (Fig. 2), the current *I* through DE jumps to a value corresponding to a new stable state (point **b** in the static characteristic in Fig. 2). After this jump, a quasi-spherical luminous CSCS appears in front of DE. By increasing *V* between the values corresponding to the points **b** and **c** (Fig. 2), the CSCS remains in a stable state. When *V* reaches the critical value corresponding to point **c** (Fig. 2), the structure becomes diffusive and the current *I* quickly decreases (jump **c** → **d** in Fig. 2), simultaneously becoming time dependent. The current oscillations are strong (with a relative amplitude of about 45 percents) and nonlinear, with many harmonics appearing in the power spectrum. These oscillations are due to the nonlinear dynamics of the DL, which consist of the periodical generation and disruption of the DL in front of DE [11]. The disruption of the DL triggers the appearance of a new DL in front of the DE, which starts its own dynamics. When the potential on the electrode is gradually decreasing, we observe that both of the current jumps are subjected to hysteresis. Thus, after the current jump **f** → **g**, the current oscillations disappear and the structure become again stable. After the current jump **h** → **i** the luminous structure disappears. The presence of hysteresis effects prove the ability of the CSCS to maintain its states (stable or oscillatory) in conditions less that than required for their emergence.

The potential threshold of the appearance of the CSCS (corresponding to point **a** in the static *I-V* characteristic in Fig. 2) strongly depends on the negative bias of RE, as shown in Fig. 3. With the increase of the negative potential on RE, the CSCS domain of stability (branch **b** → **c** on the static *I-V* characteristic in Fig. 2) can be reduced to only one point, so that the structure becomes unstable immediately after its appearance.

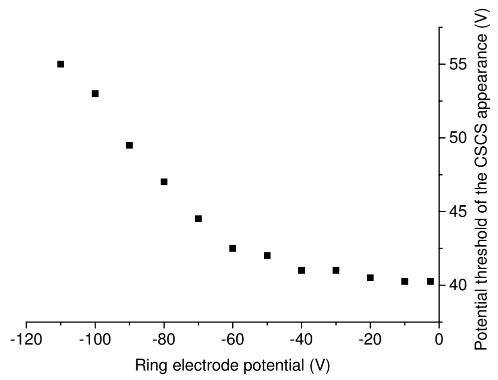

Fig. 3. Dependence of the potential threshold of the CSCS appearance on the ring electrode potential.

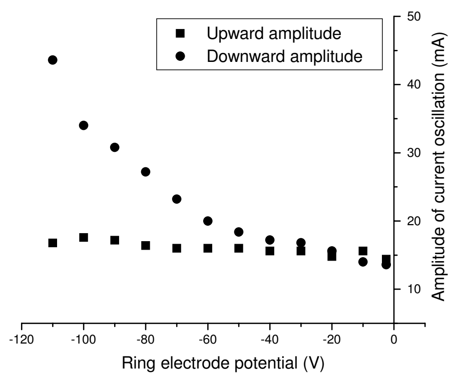

Fig. 4. Amplitude of the current oscillations versus the negative potential of the ring electrode

In the dynamic regime, we have observed a strong dependence of the amplitude and frequency of the current oscillations on the negative potential applied to RE. Thus, a negative RE-potential seems to affect especially the downward amplitudes (the signal amplitude in the negative [downward] direction relative to the dc component of the current) of the current oscillations, while the upward amplitudes (the signal amplitude in the positive [upward] direction relative to the dc component of the current) remain almost constant (see Fig. 4). This can be explained by the current limitation effect [12]. The increase of the downward amplitudes of the current oscillations leads to a decrease of the total current collected by DE. Fig. 5 shows the dependence of the current oscillation frequency on the negative potential applied to RE. This dependence occurs because the oscillation frequency depends on the dc component of the current collected by the DE [1], and this current decreases when the negative potential on RE increases.

The control of the appearance and dynamics of the CSCSs is an important task of plasma physics in view of the applications improvement. Thus, the control of the CSCS appearance plays an important role in the control of chaos in plasma devices [2]. The control of the oscillation frequency is very important for the development of the high frequency generators [13], as well as quantum photodetectors [14]. The proposed method, which uses only one additional electrode, is very simple, effective and inexpensive. It can be easily applied to a large class of devices, with very good results.

3 Conclusion

We have presented experimental results concerning the influence of a negatively biased ring electrode on the appearance and dynamics of a complex space charge structure, created on a positively biased central disk electrode immersed in plasma. Thus, the negative potential on the ring electrode increases the potential threshold of the structure emergence and reduces the stability domain of it. In the dynamic state, the negative potential on the ring electrode decreases the current collected by the disk electrode and reduces the amplitude and the frequency of the

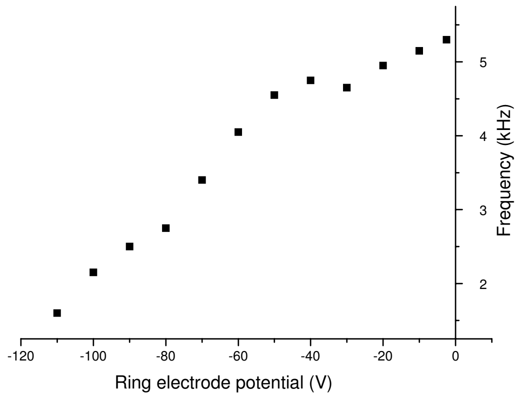

Fig. 5. Dependence of the oscillation frequency on the negative ring electrode potential.

current oscillations.

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