

## Complex space-charge configuration inside and around a grid cathode with hole

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### 1. Introduction

Complex space charge structures, in form of sheaths, double layers, fireballs, multiple fireballs or inverted fireballs are well-known phenomena appearing in regions of plasma where local constraints are applied, often in form of a localized electric field, pulling the system away from thermodynamic equilibrium. The dynamics of such structures give rise to different plasma instabilities, involving complex oscillations of the plasma parameters or chaotic states under certain experimental conditions [1-3].

We report on investigations of a complex space charge structure in a low-temperature plasma consisting of two fireball-like structures, one of them similar to an inverted fireball [1]. This configuration is obtained by a spherical metallic grid cathode with a small hole.

### 2. Experimental results and discussion

The experiments have been performed in a plasma diode of glass in which the anode is a metallic rectangular plate of 25 cm×20 cm size, while the cathode is a spherical metallic grid with a diameter of 40 mm (with 0.5 mm being the diameter of the metallic wires and 2 mm the mesh width) with a small hole with a diameter of about 6 mm. Fig. 1 shows the static current-voltage characteristics of the cathode, recorded under the following experimental conditions: argon pressure  $p = 7.5 \times 10^{-2}$  mbar, distance between anode and cathode  $d = 25$  cm. The complex structure (see Fig. 2) appears suddenly while decreasing the potential on the grid cathode with respect to the anode (i.e. making it more negative) under the value of about -282 V. The static current-voltage characteristic of the grid cathode shows a hysteretic current jump, i.e. increasing the grid potential the fireball structure disappears for a more positive value (-263 V) than the potential where it appeared during decreasing it. The threshold value of the voltage necessary for the appearance of the complex structure decreases (it is more negative) with increasing the gas pressure. Moreover, the width of the hysteresis of the static current-voltage characteristics depends also on the gas pressure.

Electrical probe measurements have shown a positive potential inside the grid cathode with respect to the potential applied on it. This is an indication for the formation of a virtual

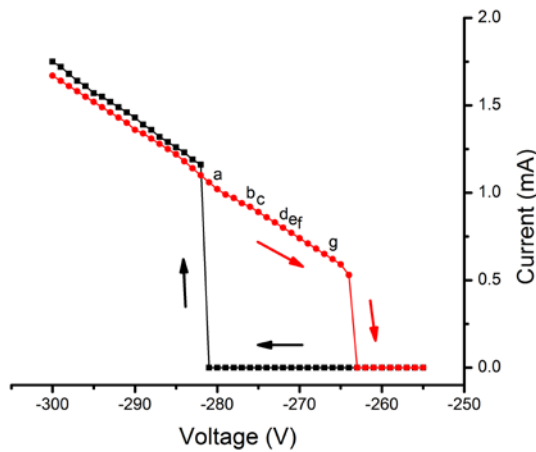


Fig. 1: Static current-voltage characteristic of the grid cathode (the letters indicate the positions where the time series of the discharge current were recorded)



Fig. 2: Complex space charge structure inside and around a grid cathode with a hole

anode inside the grid due to the electrons that perform a pendulum motion similar to the effect inside a hollow cathode. This leads to an amplification of the ionization processes and thereby to a strong increase of the ion density. Thus, we can argue that the inner fireball appears around a virtual anode inside the grid cathode. For more negative potentials, the electrons inside the grid cathode reach sufficient energy to penetrate the inner sheath near the cathode, passing through the hole and giving rise to a second fireball-like structure located outside the cathode (in the vicinity of the hole). This second structure interacts with the negative glow of the discharge (located outside the spherical grid cathode).

The time series of the discharge current reveal strongly nonlinear dynamics of the complex space charge structure. Thus, during re-increasing the grid potential, before disappearing, the structure passes through different dynamic states involving chaos, quasi-periodicity and period-doubling bifurcations, looking like a competition of different routes to chaos, as that one described in [4]. Fig. 3 shows the time series of the discharge current, their FFT's and the reconstructed attractors of the plasma system dynamics (by time delay method), respectively, for different values of the voltage applied on the grid cathode. For low values of the voltage (under  $-280$  V) the behaviour of the plasma system is a chaotic one (intermittent), as it can be observed from the time series of the discharge current in Fig. 3a. Between  $V = -276$  V and  $V = -272$  V the dynamics become quasi-periodic (see Figs. 3b-3d''), and more and more regular as the voltage increases. At  $V = -271$  V a transient phase starts (see Figs. 3e-3e''), driven by a period-doubling bifurcation and ending at  $V = -270$  V with a period-2 dynamics (see Figs. 3f-3f''). The final state of the plasma system (before the complex

structure disappears) is a periodic one (see Figs. 3g-3g''), occurring at  $V = -266$  V after a reverse (backward) period-doubling bifurcation.

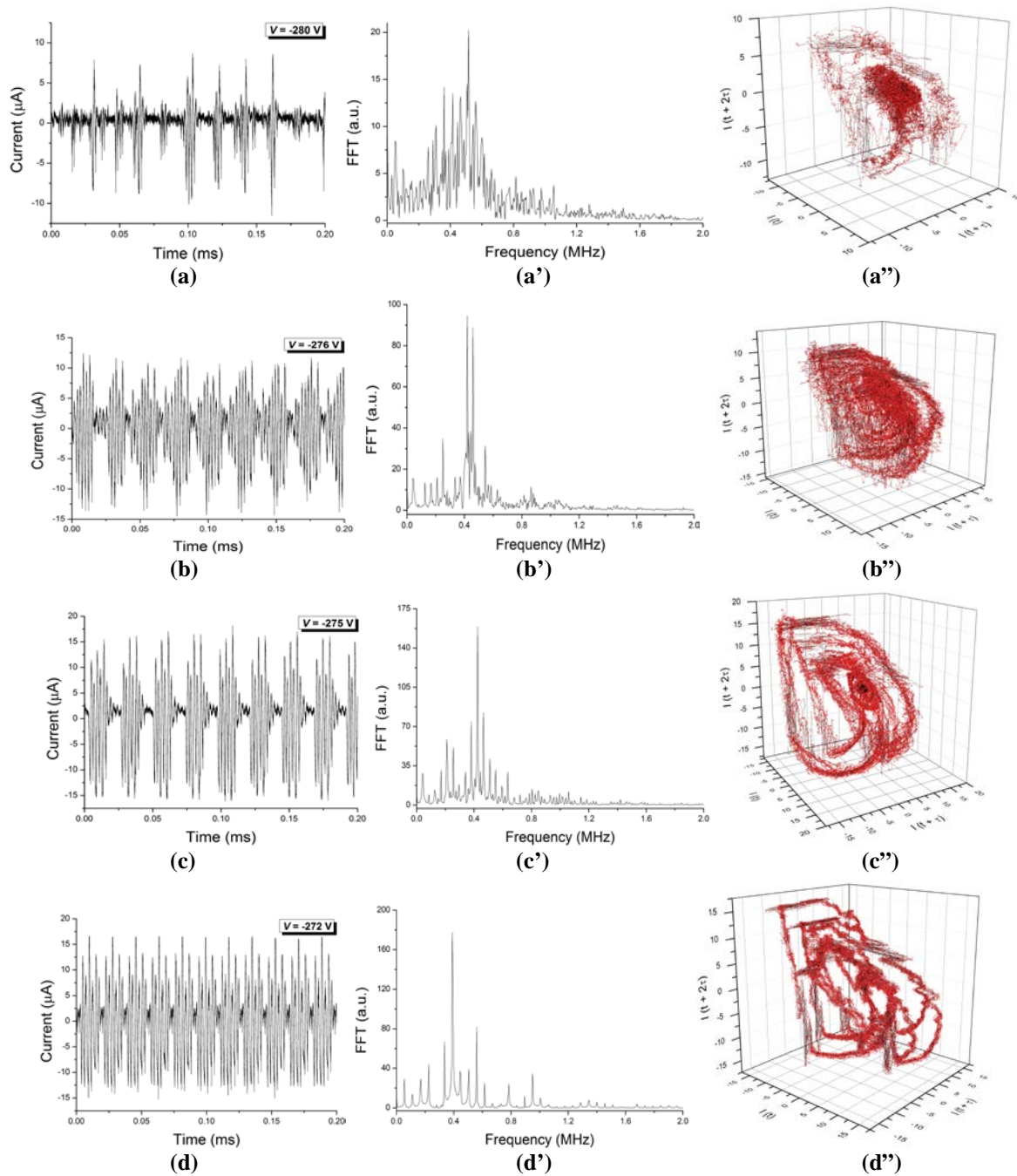


Fig. 3: Time series of the discharge current (left column), their FFT's (central column) and the reconstructed attractors of the plasma systems dynamics by time delay methods (right column), respectively, for different values of the voltage applied on the grid cathode.

### 3. Conclusion

Complex space charge configurations were obtained in low-temperature plasma inside and around a spherical grid cathode with a small hole. The structure appears at potentials below about  $-260$  V. Strong hysteresis is recorded. The dynamics of the complex space charge structure are investigated. The time series of the discharge current reveal that the increase of the

applied voltage sets in motion a series of strongly nonlinear phenomena, determining the structure to pass from chaotic/intermittent behaviour through quasi-periodicity, period-doubling to a coherent dynamics towards its disappearance.

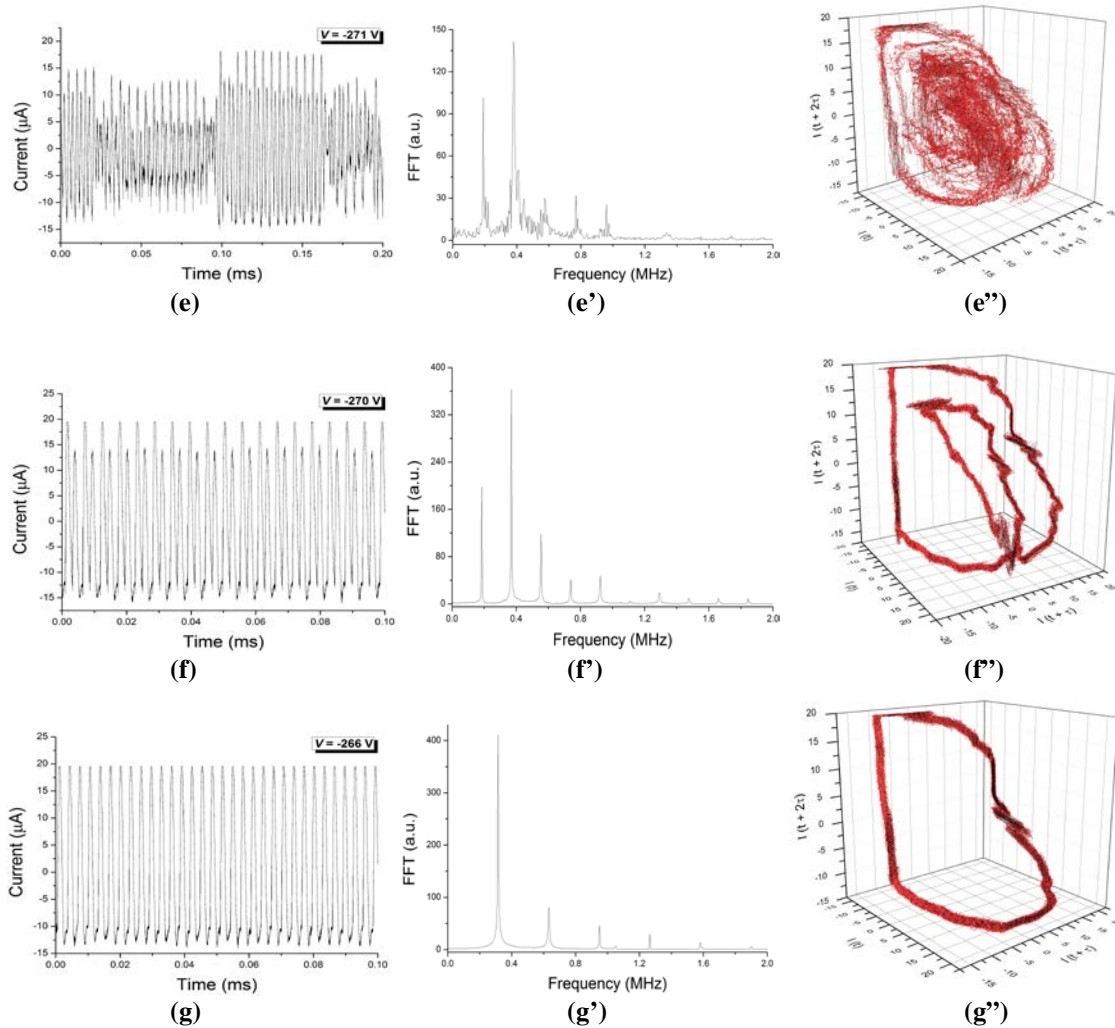


Fig. 3 (continuation)

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