Self-organization as an intrinsic feature of DC glow microdischarges: modelling appearance of different spot patterns

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Three-dimensional modelling of self-organization in DC glow microdischarges is performed and reveals the existence of multiple 3D modes associated with spot patterns similar to those found in experiments. The modelling is performed for helium in the framework of the simplest self-consistent model of glow discharges. Bifurcations of 3D solutions from other 3D solutions are found. Results found suggest that 3D self-organization is an intrinsic feature of plasmas produced in DC glow microdischarges.

The presence and/or the consequences of bifurcations have been encountered in recent modelling of DC glow microdischarges even in apparently simple situations [1]. These bifurcations are a consequence of the existence of multiple solutions in the theory of basic DC glow discharges. Some of the solutions are associated with 2D (axially symmetric) patterns of cathodic spots [2], while others are associated with 3D patterns [3] similar to those observed in experiments [4]. The pattern of 2D solutions has been established in [1, 2]. It has been suggested (see accompanying contribution) that self-organization in microdischarges observed in [4] appears to be a general phenomenon which may manifest in discharges with different gases provided that conditions are right.

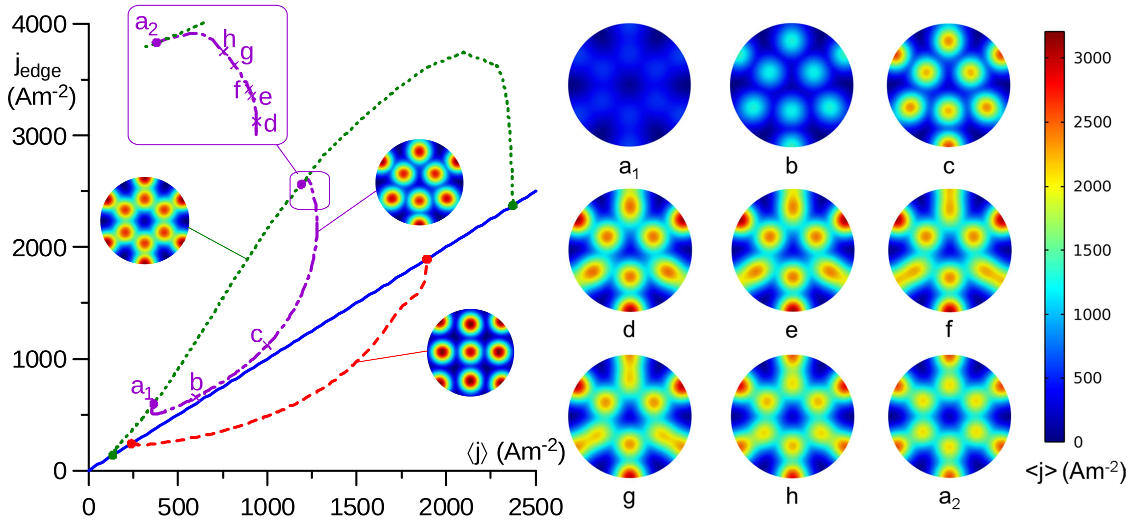
While the first steps towards self-consistent modelling of self-organization in DC glow discharges have been taken, a few questions remain unanswered. One of these questions is what is the pattern of 3D solutions? This work is concerned with the establishment of such pattern.

The modelling is performed in 3D in the framework of the simplest self-consistent model, which accounts for a single ion species and employs the drift–diffusion approximation, and for a parallel-plane discharge of the height of 0.5mm and radius of 0.5mm in helium at the pressure of 530Torr. The key feature of the modelling is the use of a stationary solver of COMSOL Multiphysics, which allows one to decouple questions of numerical and physical stability.

In this work, multiple 3D solutions are computed. Since the current-voltage characteristics of some of the 3D solutions found are overlaping and almost coincident, the solutions are more conveniently represented in the coordinates ($\langle j \rangle$, j_{edge}). Here $\langle j \rangle$ is the average current density over a cross section the discharge and j_{edge} is the current density on a fixed point at the edge of the cathode surface. In figure 1 the 1D mode and three 3D modes are shown in these coordinates as an example. The 3D modes are associated with spot patterns having a period of $\pi/3$, $\pi/4$ and $\pi/6$. Each of the 3D modes possesses two bifurcation points, one of them positioned at high discharge currents and the other at lower currents. Two of these solutions branch off from the 1D (fundamental) solution, which is in essence the classical von Engel and Steenbeck solution. Surprisingly, the 3D solution with a period of $\pi/3$ branches off from the 3D solution with a period of $\pi/6$. The former mode possesses two turning points near the bifurcations. One of these turning points is shown in detail in the inset of figure 1(a).

In figure 1(a) are shown schematics of the distribution of current density over the surface of the cathode for each 3D mode. The modes with a period of $\pi/4$ and $\pi/6$ have also been found for xenon [3] and argon (see accompanying contribution). The spot patterns associated with each mode resemble those observed in the experiments [4].

It should be mentioned that it was computed one more 3D mode with period $\pi/3$ that branches off from the mode with period of $\pi/6$, although this mode is not shown in figure 1(a). The associated



(a) (b)

Fig. 1: (a): Bifurcation diagram. Solid: 1D mode. Dashed: 3D mode with period of π/4. Dotted: 3D mode with period of π/6. Dashed-dotted: 3D mode with period of π/3. Circles: bifurcation points. Crosses: states for which distribution of current density over the surface of the cathode are shown in figure 1(b). (b): Distribution of current density over the surface of the cathode for states belonging to the mode with period π/3.

spot pattern comprises three spots at the periphery of the cathode, three interior spots and a central spot and it also resembles patterns observed in the experiments [4].

In figure 1(b) it is shown the evolution of the spot pattern associated with the 3D mode with period π/3. The states to which each distribution corresponds to are shown in figure 1(a). It can be seen how does the change of spot pattern happens: three of the spots at the periphery of the cathode merge with the nearest spot inside the cathode and the resulting spot is located off the periphery, cf. distributions for states a_2 - d. The merging happens for alternating pairs of spots and thus the period of the 3D mode is doubled.

In summary, the existence of 3D modes in DC glow microdischarges in helium is demonstrated numerically. Although the model employed is very basic, it retains the most relevant mechanisms contributing for self-organization, which are ionization and transport of charged particles. The existence of secondary bifurcations is also demonstrated and the spot patterns associated with the 3D modes resemble those observed in experiments [4]. The results found constitute a further indication that 3D self-organization is an intrinsic feature of the plasmas produced in DC glow microdischarges.

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