Modelling self-organization in DC glow microdischarges: new 3D modes

P. G. C. Almeida(*), M. S. Benilov, and D. F. N. Santos

CCCEE, Universidade da Madeira, Largo do Município,
9000 Funchal, Portugal
(*) pedroa@uma.pt

Seven new 3D modes of self-organization in DC glow discharges are computed in the framework of the simplest self-consistent model of glow discharge. Some of the modes branch off from and rejoin the 1D mode, while others bifurcate from a 2D or a 3D mode. The patterns associated with computed 3D modes are similar to patterns observed in the experiment. The computed transition from a spot pattern comprising five spots into a pattern comprising a ring spot also was observed in the experiment.

Self-organization in DC glow microdischarges has been observed for the first time a decade ago [1] and represents a very interesting and potentially important phenomenon. Since then, a number of experimental reports on this phenomenon have been published, e.g. [2], as well as a theoretical interpretation in terms of mutiple solutions existing in the theory of glow discharge [3-5].

This contribution is concerned with computing some 3D modes of self-organization which have been observed in the experiment but not in the modelling. This includes modes associated with two to six spots observed, e.g., in [2, 7], and a transition from a 3D mode with several spots into a 2D with a ring spot mode that has been observed in [7] and suggests the existence of the corresponding bifurcation.

The numerical model is identical to that described in [3]. Modelling is performed for a cylindrical discharge vessel with interelectrode gap of 0.5mm and radius of 0.5mm for xenon at 30Torr.

Figure 1 depicts the current-voltage characteristics (CVC) of the 1D mode and of the first five multimensional modes. (Here <j> is the average current density evaluated over a cross section of the discharge vessel; U is the discharge voltage.) The schematics in this figure illustrate distributions of current density on the cathode surface associated with each mode. It is interesting to note a retrograde section in the CVC of the mode a_2b_2, which is seen in figure 1b in a narrow current range around 280Am^{-2}.

The evolution with <j> of the cathodic spot patterns associated with each mode shown in figure 1 is depicted in figure 2. The computed patterns are similar to the ones observed experimentally, a difference between them is that in the modelling the spots are positioned at the periphery and not inside the cathode. However this difference will disappear if neutralization of charged particles at the wall of the discharge vessel is taken into account [6].

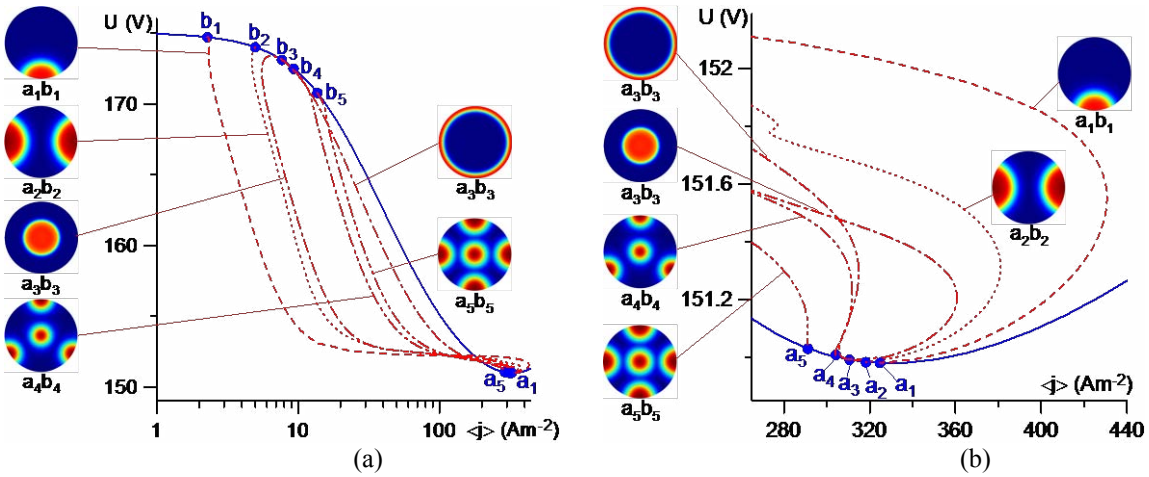
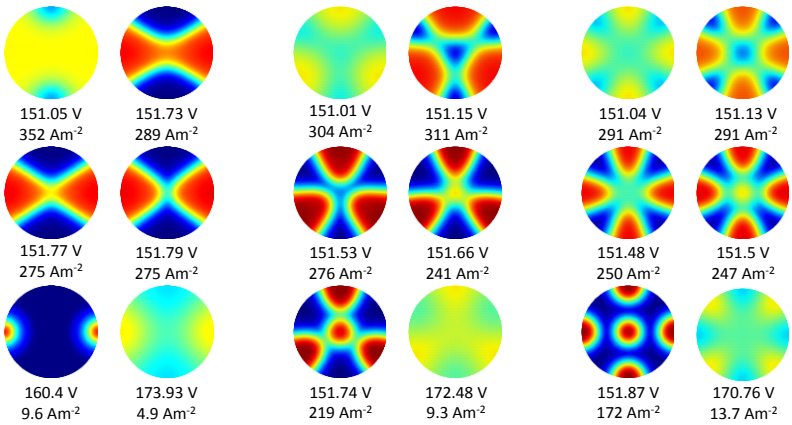
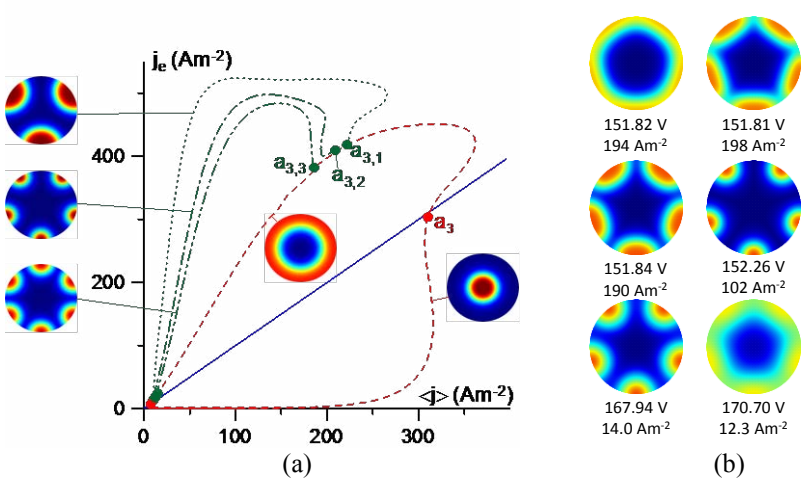


Fig. 1: CVCs. Xe, 30 Torr. Solid: the 1D mode. Dashed-dotted: 2D mode a_3b_3. Other lines: different 3D modes. Circles: bifurcation points. a): General view. b): Details near the point of minimum of the CVC of the 1D mode.



(a) (b) (c)

Fig. 2: Evolution of distributions of current on the surface of the cathode associated with different modes. Xe, 30 Torr. a): mode a_2b_2. b): a_4b_4. c): a_5b_5.



(a) (b)

Fig. 3: Xe, 30 Torr. (a) Bifurcation diagram. Solid: the 1D mode. Dashed: 2D mode a_3b_3. Other lines: 3D modes. Circles: bifurcation points. b): Evolution of distribution of current on the surface of the cathode associated with the mode $a_{3,2}b_{3,2}$.

Three third-generation modes bifurcating from the mode a_3b_3, designated $a_{3,1}b_{3,1}$, $a_{3,2}b_{3,2}$, $a_{3,3}b_{3,3}$, are shown in figure 3. They branch off and rejoin the mode a_3b_3. The mode $a_{3,1}b_{3,1}$ is associated with a spot pattern comprising three spots at the periphery of the cathode. $a_{3,2}b_{3,2}$ and $a_{3,3}b_{3,3}$ are associated with five and, respectively, six spots at the periphery. The evolution of the spot patterns associated with the mode $a_{3,2}b_{3,2}$ is shown in figure 3b.

The patterns associated with computed 3D modes with two, three, four, five and six spots at the periphery of the cathode and three spots at the peryphery and a spot at the centre are similar to patterns observed in the experiment. The transition from a spot pattern comprising five spots into a pattern comprising a ring spot also was observed in the experiment.

Acknowledgments

Work supported by FCT of Portugal through projects PTDC/FIS-PLA/2708/2012 and PEst-OE/MAT/UI0219/2011, and through the PhD grant SFRH/BD/85068/2012.

References

[1] K. H. Schoenbach, M. Moselhy and W. Shi, *Plasma Sources Sci. Technol.* **13** (2004) 177-185.
[2] N. Takano and K. H. Schoenbach, *Plasma Sources Sci. Technol.* **15** (2006) S109-S117.
[3] P. G. C. Almeida, M. S. Benilov and M. J. Faria, *Plasma Sources Sci. Technol.* **19** (2010) 025019.
[4] P. G. C. Almeida, M. S. Benilov and M. J. Faria, *IEEE Trans. Plasma Sci.* **39** (2011) 2190-2191.
[5] P. G. C. Almeida and M. S. Benilov *Phys. Plasmas* **20** (2013) 101613.
[7] W. Zhu, P. Niraula, *Private communication* (2014).