Spots on cathodes of DC glow and arc discharges: self-organization theory and its applications

M. S. Benilov

Departamento de Física, Universidade da Madeira, Largo do Município, 9000 Funchal, Portugal

Abstract
The existence of multiple modes of current transfer to electrodes of gas discharges is rather the rule than the exception. In particular, it has been known since the early 1950s that current transfer to cathodes of high-pressure DC arc discharges can occur in the diffuse mode, where the current is distributed over the front surface of the cathode in a more or less uniform way, or in the spot mode, where most of the current is localized in a small area (cathode spot). Similarly, it has been known for many decades that current transfer to cathodes of DC glow discharges can occur in the abnormal mode or in the mode with a normal spot. Recently, also modes with steady-state patterns of several spots have been observed in microdischarges in xenon; e.g., [1,2].
Different modes of current transfer to electrodes of DC gas discharges are of considerable scientific interest and of critical importance for design of a number of technical devices. Although this topic has been under intensive investigation for several decades, self-consistent theoretical models started to emerge only in the 1990s. A key step was a realization of the fact that different steady-state modes of current transfer represent self-organization phenomena and as such are intimately related to existence of multiple stationary solutions existing at the same discharge current. Such solutions must be admitted by any adequate theoretical model, including the most basic ones. Another key step was a realization of the necessity to use stationary solvers in order to compute the multiple solutions. Note that the usual approach to computing a steady state in gas discharge modelling is to follow relaxation in time of a solution given by a non-stationary solver. Only stable states can be found in this way. However, the possibility to compute a mode in the whole range of its existence, including sections where it is unstable, is indispensable for understanding the origin of different modes and finding them. Such possibility is provided by stationary solvers, which use iterative processes that need not be equivalent to relaxation in time and hence allow decoupling physical and numerical stability.
The first multiple solutions describing spots on cathodes of high-pressure arc discharges were obtained with the use of a home-made FORTRAN code implementing a stationary solver based on the Newton linearization with a direct (non-iterative) solution of linear equations in finite differences. (Note that this code is used as an engine of a free online tool for modelling plasma-cathode interaction in high-pressure arc discharges [3].) Later on, commercial software COMSOL Multiphysics has emerged, and this software provides stationary solvers based on a similar technique. COMSOL provides also an eigenvalue solver, which can be used for investigation of stability of different steady states.
In the case of cathodes of high-pressure arc discharges, a reasonably complete theory has been developed along these lines [4], mostly for low-current arcs used in high-intensity discharge lamps. The theory has been convincingly validated by extensive experimental data. In the case of glow cathodes, the theory started to emerge only recently [5-7]. In both cases, multiple axially symmetric and 3D stationary solutions describing different spot modes have been found and their stability investigated with the use of the stationary and eigenvalue solvers of COMSOL Multiphysics.
Although physical mechanisms of current transfer to glow (cold) and arc (hot) cathodes are very different, the overall patterns of self-organization leading to appearance of different modes in both cases are remarkably similar [5]. Identification and understanding of these similarities facilitate research in both fields.
This talk is concerned with a review of the above-described advances.

Acknowledgments The work was supported by FCT of Portugal (projects PTDC/FIS/68609/2006 and PEst-OE/MAT/UI0219/2011).

References

[1] Zhu W, Takano N, Schoenbach K H *et* al 2007 Direct current planar excimer source *J. Phys. D: Appl. Phys* **40** 3896-3906.

[2] Schoenbach K H and Zhu W 2012 High-pressure microdischarges: sources of ultraviolet radiation *J. Quant. Elect.* (to appear).

[3] http://www.arc_cathode.uma.pt/tool/index.htm

[4] Benilov M S 2008 Understanding and modelling plasma-electrode interaction in high-pressure arc discharges: a review *J. Phys. D: Appl. Phys* **41** 144001

[5] Almeida P G C, Benilov M S, Cunha M D and Faria M J 2009 Analysing bifurcations encountered in numerical modelling of current transfer to cathodes of dc glow and arc discharges *J. Phys. D: Appl. Phys.* **42** 194010.

[6] Almeida P G C, Benilov M S and Faria M J 2010 Multiple solutions in the theory of dc glow discharges *Plasma Sources Sci. Technol* 1**9** 025019.

[7] Almeida P G C, Benilov M S and Faria M J 2011 Three-dimensional modeling of self-organization in dc glow microdischarges *IEEE TPS* **39** 2190-2191.