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AXIALLY SYMMETRIC MODES OF CURRENT TRANSFER TO CATHODES OF DC GLOW DISCHARGES AND THEIR STABILITY

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It is well known that current transfer to glow cathodes occurs in the abnormal mode at high currents and in the normal mode at lower currents. Recently, observations of patterns of more than one spot in DC glow microdischarges have been reported (e.g., [1-3]).

It was hypothesized quite some ago that different modes are described by multiple solutions that should exist in the theory of DC glow discharges; see discussion and references in [4]. These multiple solutions were actually computed only very recently [4]. In this work, additional results on these multiple solutions are given along with results on stability of these solutions.

The simulations are based on a simple model of a DC glow discharge comprising transport equations for a single ion species and the electrons written in the drift-diffusion approximation and the Poisson equation. Boundary conditions at the cathode and anode are written in the conventional form. One boundary condition at the wall of the discharge vessel is zero electric current density. Two boundary conditions are used alternatively for the density of the charged particles at the wall: diffusion losses to the wall are either neglected (no-flux conditions) or taken into account (zero-density conditions). The discharge tube was assumed to be axially symmetric. Steady-state solutions describing different modes of discharges in such tubes may be axially symmetric or 3D. In this work, axially symmetric (and 1D) steady-state solutions are given and their stability against axially symmetric and 3D perturbation modes analyzed.

Typical current-voltage characteristics (CVCs) are shown in Fig. 1. The mode of current transfer which is represented by the solid line is 1D. This mode exists at all values of the discharge current and will be designated fundamental mode. The dashed and dashed-dotted lines represent the first 2D mode, which exists in a limited current range and is associated with spot patterns.

Stability of steady-state solutions was investigated along the same lines as in the investigation of stability of current transfer to cathode of high-pressure arc discharges [5]. In particular, the steady-state problem governing axially symmetric solutions and the eigenvalue problem for 3D perturbations of these solutions were solved separately by means of COMSOL Multiphysics. Since 3D perturbations of axially symmetric steady states are harmonic with respect to the azimuthal angle, the eigenvalue problems governing stability against each of the harmonics may be formulated in 2D. Therefore, it is sufficient to solve a series of 2D eigenvalue problems governing stability against different harmonics, in order to obtain a complete spectrum of perturbations of an axially symmetric steady state solution.

Stability was investigated assuming that the power supply maintains the discharge current fixed. Production and removal of the ions were assumed to be the only processes with explicit dependence on time; all the other processes were considered as quasi-stationary. In other words, the only non-stationary term taken into account was the one in the ion conservation equation. The

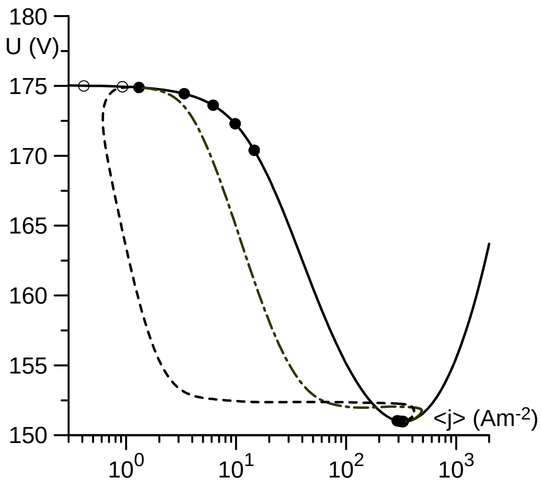

Fig. 1: CVCs of discharge in Xe. *p* = 30 Torr, discharge tube of 1.5 mm radius and 0.5 mm height, diffusion losses to the wall neglected. Solid: fundamental mode. Dashed, dashed-dotted: branches of the first 2D mode associated with patterns with and, respectively, without a spot at the center of the cathode. Open circles: bifurcation points where two initial 3D modes branch off from the fundamental mode. Full circles: bifurcation points where 2D modes branch off from the fundamental mode.

usual procedure of the linear stability theory was used in order to obtain the eigenvalue problem for perturbations.

Typical results of numerical investigation of stability were as follows. The fundamental mode is stable except at the section between the bifurcation points of the first 3D mode, in agreement with the theory [6]. Results on stability of the 2D modes conform to the theory [6] in the vicinity of the bifurcation points, as they should, and reveal alternations of stability of a steady-state 2D mode against the same 3D perturbation mode, including against the first and the second ones. Due to this phenomenon, the first 2D mode without diffusion losses to the wall is stable in certain ranges of electric current, in contrast to what has been found in the case of the arc discharge, where the first 2D steady-state mode is always unstable [7]. All the others 2D modes are always unstable.

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References

[1] K. H. Schoenbach, M. Moselhy and W. Shi, 2004 *Plasma Sources Sci. Technol.* **13** 177
[2] N. Takano and K. H. Schoenbach, 2006 *Plasma Sources Sci. Technol.* **15** S109
[3] W. Zhu, N. Takano, K. H. Schoenbach, D. Guru, J. Mclaren, J. Heberlein, R. May and J. R. Cooper, 2007 *J. Phys. D: Appl. Phys.* **40** 3896
[4] P. G. C. Almeida, M. S. Benilov and M. J. Faria, 2010 *Plasma Sources Sci. Technol* (to appear)
[5] M. S. Benilov, M. D. Cunha and M J Faria, 2009 *J. Phys. D: Appl. Phys.* **42** 145205
[6] P. G. C. Almeida, M. S. Benilov, M D Cunha and M. J. Faria, 2009 *J. Phys. D: Appl. Phys.* **42** 194010
[7] M. S. Benilov and M. J. Faria, 2007 *J. Phys. D: Appl. Phys.* **40** 508