Fluid Modelling of Dielectric Barrier Discharges for Plasma Technology

A. P. Jovanović, M. N. Stankov, D. Loffhagen, M. M. Becker
Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany

INTRODUCTION: COMSOL Multiphysics® with LiveLink™ for Matlab® is used for the numerical analysis of dielectric barrier discharges (DBDs), which are widely used in various fields of plasma technology, such as surface processing, plasma medicine, and agriculture. The present contribution highlights how the module LiveLink™ for Matlab® is used to automatically build up complex models of DBDs in spatially 1D and axisymmetric 2D geometries. The COMSOL® models thus generated are used to study the physical properties of non-thermal plasmas generated by diffuse and filamentary DBDs in argon at different conditions.

COMPUTATIONAL METHODS: The fluid-Poisson model for non-thermal plasmas in DBDs consists of continuity equations for the particles number densities of all relevant plasma species

$$\frac{\partial n_p}{\partial t} + \nabla \cdot \mathbf{\Gamma}_p = S_p,$$

the electron energy balance equation

$$\frac{\partial w_e}{\partial t} + \nabla \cdot \mathbf{Q}_e = -e_0 \mathbf{E} \cdot \mathbf{\Gamma}_e + \widetilde{S}_e, \text{ where } \mathbf{E} = -\nabla\phi\,,$$

Poisson's equation for the potential

$$-\varepsilon_0 \varepsilon_r \nabla^2 \phi = \sum_p q_p n_p,$$

and a balance equation for surface charges accumulating on the dielectric surfaces [1]:

$$\frac{\partial \sigma}{\partial t} = \sum_p q_p \mathbf{\Gamma}_p \cdot \boldsymbol{\nu}\,.$$

The application of COMSOL Multiphysics® for studying large systems with tens of species and hundreds of reactions is simplified by the in-house toolbox MCPlas, which combines the features of MATLAB® and COMSOL Multiphysics® via LiveLink™ for MATLAB®:

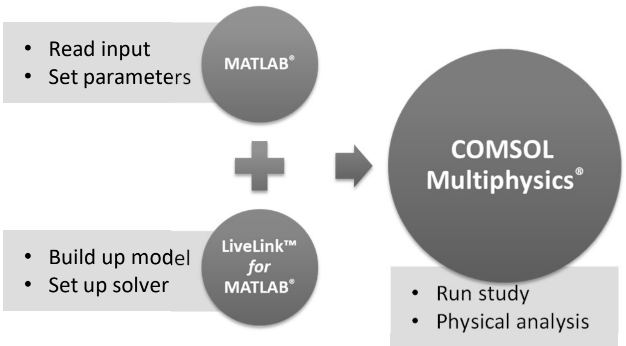

Figure 1. Workflow for the analysis of DBDs using the MCPlas toolbox.

RESULTS: The application of the toolbox MCPlas is illustrated by two case studies: 1D modelling of a diffuse DBD in argon at 500 mbar and 2D modelling of the streamer propagation in a single-filament DBD in argon at atmospheric pressure. The first example involves continuity equations for 22 species with about 400 reactions, while the second example includes 6 species and 13 reactions.

CASE STUDY 1: Diffuse DBD in argon at 500 mbar

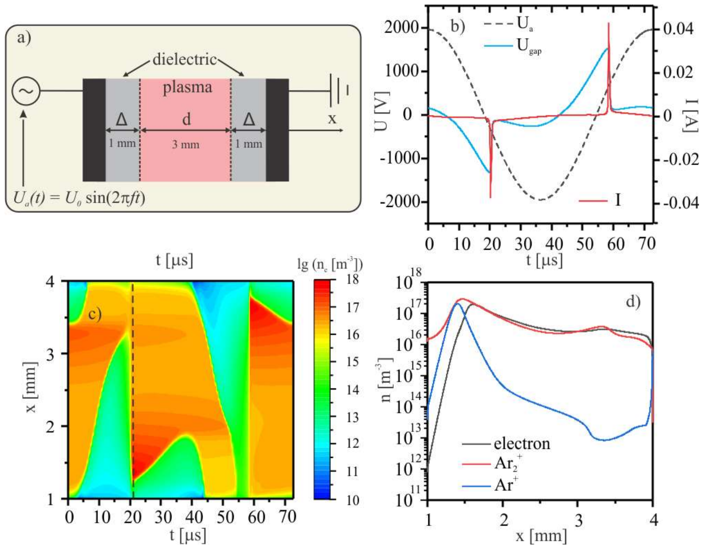

Figure 2. Periodic evolution of a diffuse DBD in argon with applied voltage U_0 = 2 kV, frequency f = 13 kHz, pressure p = 500 mbar obtained by 1D modelling: a) geometry of the model, b) applied voltage, gap voltage, and electric current, c) spatiotemporal behaviour of the electron number density and d) spatial distribution of number densities of electrons, Ar_2^+ and Ar^+ at the moment of maximum current (negative polarity).

CASE STUDY 2: Streamer propagation in filamentary DBD

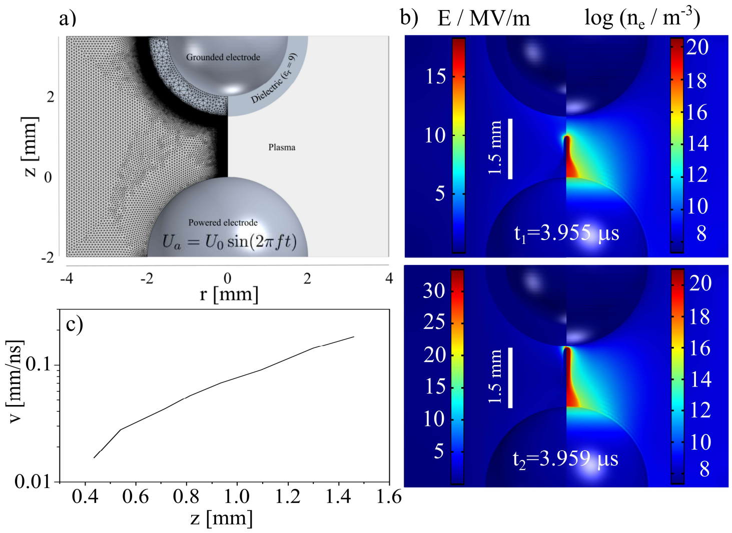

Figure 3. Results of 2D modelling of the streamer propagation in a single-filament atmospheric-pressure DBD in argon with U_0 = 3 kV, f = 60 kHz, d = 1.5 mm: a) schematic diagram of the asymmetric DBD configuration and used mesh, b) spatial profile of the electric field and the electron number density at t_1 and t_2, and c) axial variation of the streamer velocity v.

CONCLUSIONS: The LiveLink™ for MATLAB® module provides powerful tools to combine the functionalities of MATLAB® and COMSOL Multiphysics®. The MATLAB-COMSOL toolbox for plasma modelling, MCPlas, exploits these features to automate the construction of complex plasma-physical models in COMSOL as illustrated by two different test cases.

REFERENCES:

[1] M. M. Becker *et al.*, Analysis of microdischarges in asymmetric dielectric barrier discharges in argon. *J. Phys. D: Appl. Phys.* **46** (2013) 355203

Excerpt from the Proceedings of the 2020 COMSOL Conference