Simulations of positive and negative streamers in the AMReX environment

Ilija B. Simonović, Danko V. Bošnjaković and Saša Dujko

Institute of Physics, University of Belgrade, P.O. Box 68, 11080 Belgrade, Serbia
E-mail: isimonovic@ipb.ac.rs

Streamers are thin channels of weakly-ionized nonstationary plasma produced by an ionization front that moves through non-ionized matter (Teunissen and Ebert 2017). They have applications in diverse areas of science and technology ranging from their role in creating lighting and sprite discharges in the upper planetary atmospheres to industrial applications such as the ignition of high-intensity discharge lamps and treatment of polluted gases and water. Further optimization and understanding of such applications are dependent on an accurate knowledge of streamer properties, electron transport and physical processes involved.

We have developed a computer code that implements an axisymmetric first order fluid model in the AMReX environment. AMReX is an open-source C++ library for numerical calculations with block structured adaptive mesh refinement (Zhang et al. 2019). It has inbuild geometric multigrid solvers and it allows both MPI and OpenMP parallelization, as well as parallelization on graphic processing units. AMReX also has many inbuilt classes which enable a convenient implementation of both grid and particle data.

In our code the time evolution of the number density of electrons is represented by the drift-diffusion-reaction equation. The time evolution of the number densities of positive and negative ions are represented by the rate equations, as ions are assumed to be stationary for the timescales of our simulations. The time integration of these equations is performed by employing the second order Runge-Kutta method. The spatial dependence of transport coefficients in these equations is represented by the local field approximation. The electric potential due to space charges is determined by solving the Poisson equation, while photoionization is represented by solving a set of Helmholtz equations. These equations are solved by employing the AMReX inbuilt geometric multigrid solver. Bourdon three term parametrization (Bourdon et al. 2007) is employed for representing photoionization in the mixtures of nitrogen and oxygen.

Spatial discretization is implemented by using the finite volume method. Thus, scalar variables are defined at the cell centers, while vector variables are defined at the cell faces. For this reason, the number density of electrons needs to be interpolated from cell centers to cell faces to calculate the electron flux. For this purpose, both TVD scheme with the Koren flux limiter (Koren 1993) and Munz implementation (Munz 1988) of the MUSCL scheme (Van Leer 1979) can be used. The validity of the code is tested by comparing its results to the results of the Afivo-streamer open-source fluid code (Teunissen 2017).

Acknowledgments

This work is supported by the Science Fund of the Republic of Serbia, Grant No. 7749560, Exploring ultra-low global warming potential gases for insulation in high-voltage technology: Experiments and modelling EGWIn.

References

Bourdon, A., Pasko, V. P., Liu, N. Y., Célestin, S., Ségur, P. and Marode, E., 2007, Plasma Sources Sci. Technol. 16, 656

Koren, B., 1993, In Numerical Methods for Advection-Diffusion Problems, pages 117–138. Braunschweig/Wiesbaden: Vieweg

Munz, C. D., 1988, J. Comput. Phys., 77, 18

Teunissen, J. and Ebert, U., 2017, Journal of Physics D: Applied Physics 50, 474001

Van Leer, B, 1979, Journal of computational Physics, 32, 101

Zhang, W. et al., 2019, Journal of Open Source Software, 4, 1370