Modelling heat dominated electric breakdown in air with adaptivity to electron or ion timescales

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We simulate heat dominated electrical breakdown in air in a short planar gap by coupling the discharge dynamics with the air dynamics. The electric discharge model is of diffusion drift reaction type for electrons, positive and negative ions, including secondary electron emission from the cathode. The air dynamics is modelled with the Euler equations and an energy balance equation for the heat. To follow the discharge dynamics over sufficiently long times, we derived a reduced model on the ion timescale from the full model on the electron timescale, and we switch to the reduced model when appropriate. We discuss in detail the implementation of a time-adaptive numerical scheme. We use this scheme to simulate the short and long time dynamics. As the electric discharge develops the air temperature rises due to Ohmic heating. The heated air expands, and the transport and reaction coefficients of the discharge change accordingly. We observe electric breakdown in an initially undervolted gap through a sequence of ionization waves.

1. Introduction

Gas heating in electrical discharges has been studied in the context of fast gas heating, plasma-assisted combustion, atmospheric lightning etc. The majority of simulation studies so far pertaining to gas heating in atmospheric pressure discharges have been performed in 0D or 1D approximation. The large difference in timescales between electron dynamics on the one hand and ion dynamics and gas movement on the other hand makes computations very expensive. Recently 2D axisymmetric simulations [1-3] have been published, but they are either only on the ion or only on the electron time scale. Here we overcome this limitation and study the long time dynamics.

2. Methodology

We simulate the dynamics in a short planar gap in 2D (r-z coordinates) with secondary electron emission where ionization grows due to Ohmic heating rather than through space charge dominated streamer breakdown. This dynamics is challenging to simulate as in the initial stage the electron dynamics has to be followed, and later on the much slower ion dynamics has to be resolved, and both have to be coupled to the hydrodynamics of the medium. We present a model on the time scale of ion motion, that is a reduced version of the full discharge dynamics; it is a generalization of the reduced model introduced in [4] where it was applied to study the transition from Townsend to glow discharge. Our calculations are adaptive in time, i.e., we switch between the full model on the electron time scale and the reduced model on the ion time scale as required. We also discuss possible numerical switching criteria.

3. Results

We developed and employed the 2D cylindrically symmetric model to simulate heat dominated electric breakdown in air. We observe a cyclic process whereby the positive ions hit the cathode, liberate electrons via secondary emission and these electrons feed the discharge channel by producing more electrons and ions via impact ionization. Ohmic heating causes the temperature of the gas to rise. Eventually, the heated gas expands resulting in electric breakdown near the discharge axis. Detailed results are submitted [5].

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5. References

[1] A. Agnihotri, W. Hundsdorfer and U. Ebert, Jap. J. Appl. Phys. **55** (2016) 07LD06.

[2] F. Tholin and A. Bourdon: J. Phys. D, Appl. Phys. **46** (2013) 365205.

[3] A. Komuro and R. Ono, J. Phys. D, Appl. Phys. **47** (2014) 155202.

[4] D. D. Sijacic, U. Ebert and I. Rafatov, Physical Review E. **71** (2005) 066402.

[5] A. Agnihotri, W. Hundsdorfer and U. Ebert, submitted to Plasma Sources Sci. Technol.