Comparing Fluid Models for Streamer Discharges

Streamer discharges are rapidly growing ionized filaments that appear in gases, liquids and solids exposed to strong electric fields. Their space charge enhances the electric field around their tips, which drives their growth and controls much of their dynamics.

Streamer discharges have applications in diverse areas of science and technology. The optimization and understanding of these applications depends on an accurate description of the electron dynamics. However, streamer models face basic plasma physics challenges, because they are strongly non-linear transient discharges that have high ionization density gradients. Here we consider plasma fluid models, which describe the electron dynamics in a plasma based on macroscopic quantities like electron density, average electron velocity, average electron energy etc.

Plasma fluid models are constructed by taking velocity moments of the Boltzmann equation. Depending on the number of moments considered and on the closure assumptions, different fluid models have been derived over the last decades [1-4]. Three plasma fluid models are considered in this work: the first order reaction-drift-diffusion model based on the local field approximation (LFA); the second order reaction-drift-diffusion model based on the local energy approximation (LEA) and a recently developed high order fluid model [5]. We investigate how well these models can simulate negative ionization fronts in one dimension by comparing them with a PIC code. Such ionization fronts can be seen as the one-dimensional equivalent of streamer channels.

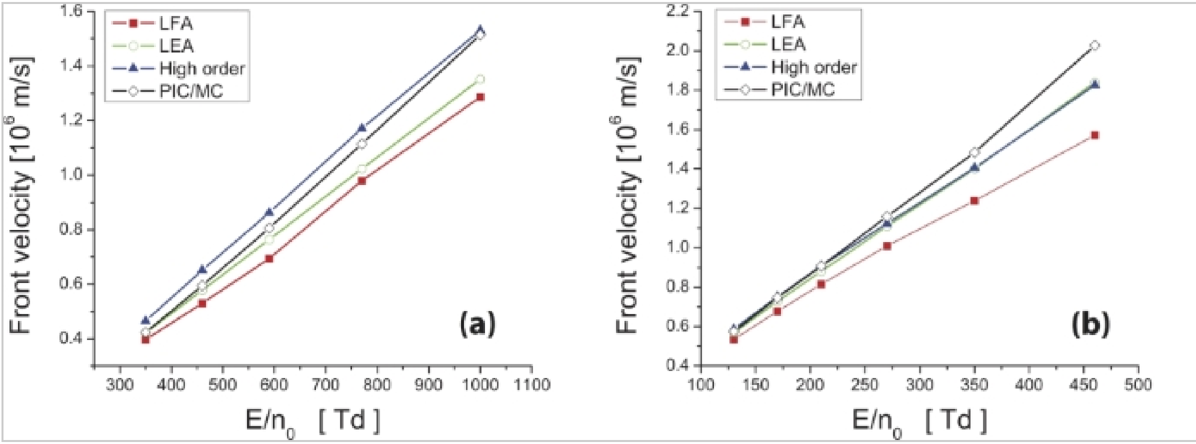

Figure 1. Expand for full caption

In Figure 1 we compare velocities of planar fronts in neon (a) and in nitrogen (b) as a function of the electric field for the different models. In both gases, the LFA model shows the largest deviation from the PIC/MC results. The front velocity is always underestimated with this model, with larger deviations at higher fields. One cause is that the local field approximation contains no explicit equation for energy transport. The LEA and the high-order model include energy transport, which leads to higher electron energies at the edge of the front, and thus to faster growth and better agreement with PIC simulations.

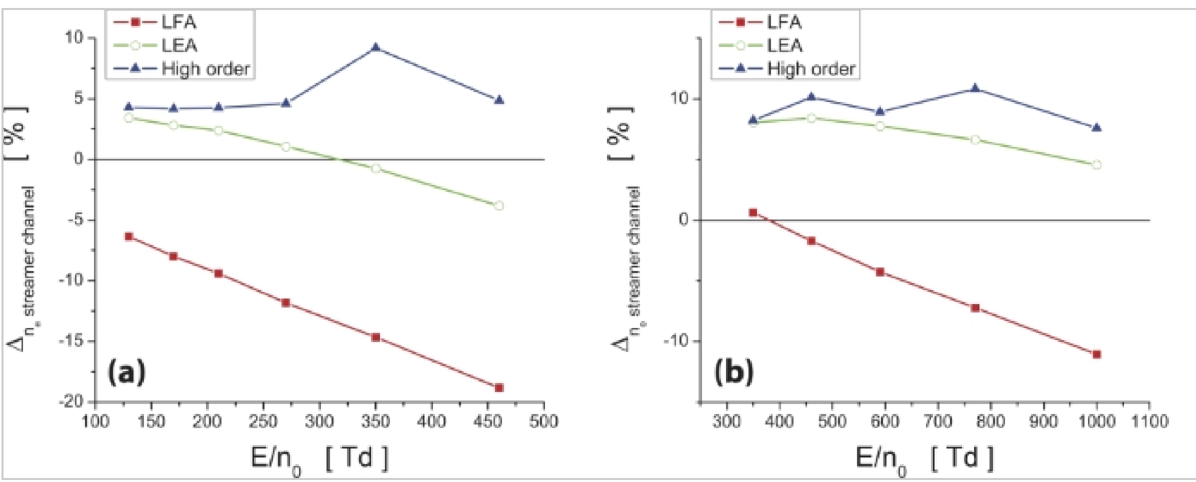

Figure 2. Expand for full caption

In Figure 2 we compare the electron density in the fluid models to PIC/MC simulations as a function of reduced electric field, in neon (a) and in nitrogen (b). In neon, the LFA model shows the largest deviation: it systematically underestimates the electron density by up to 18% and 13% for neon and nitrogen, respectively. The difference is larger for higher electric fields. The LEA model does slightly better than the high-order model, both showing deviations of up to 5%.

The classical LFA model is the simplest model considered. Despite the simplifying assumptions present in the model, we find that the LFA model gives reasonably good results. Of course, it can not accurately calculate the electron energy, but if one is interested in general characteristics like velocity, ionization level or the general shape of the discharge, this model can be a good choice. Both the LEA and the high-order model give good predictions for the energy profile in the channel, but the high order model gives a better description of the energy slope in the discharge front.

Read the complete article in ***Plasma Sources Science and Technology***.

References

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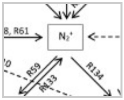

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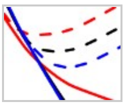

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