Simulations based on moment multi-fluid models for low-temperature plasmas at low pressure

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Résumé

Although particle-in-cell simulations provide a very accurate description of the state of a plasma, they are computationally very expensive and remain unaffordable to study full-domain 3-D geometries. For that reason, hybrid and fluid descriptions are a sound alternative in low-temperature plasma discharges that can represent more efficiently the macroscopic scales. Nevertheless, the fluid models rely on the transport models and the accuracy of numerical discretization schemes in order to provide a meaningful solution.

Most of the fluid models assume charge neutrality and neglect the electron inertia. By doing this, the numerical discretization does not need to resolve the electron plasma frequency and the Debye length, which are in most of the cases much smaller than the macroscopic scales of interest. Nevertheless, these assumptions do not allow for capturing the plasma sheath. Additionally, some electrostatic waves such as the electron cyclotron drift instability that is present in some $E \times B$ devices, are not fully explained with simplified fluid models. Furthermore, some of the fluid codes neglect the ion temperature as it is much lower than this of electrons.

In this paper, we present a novel strategy that is based on moment multi-fluid models for the simulation of low-temperature plasmas. The objective of the model is to self-consistently capture, in an efficient manner, the important kinetic effects in low pressure plasmas. The fluid model simulates the evolution of the macroscopic quantities. A novel numerical scheme will be presented in this work. The computational model proves to solve accurately both the electrons and the heavy species (ions and neutrals) fluids, while keeping the electron inertial terms. The fluid description is computationally more efficient than the kinetic model. However, it fails to capture some important kinetic information. For that reason, the higher moments of the electron kinetic equation will be solved. The numerical algorithm can be applied to different low-temperature plasmas under low-pressure conditions applications, such as Hall thrusters.

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