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A Time-Dependent Study of Radio-Frequency Plasma Sheaths Using the Flux-Corrected Transport (FCT) Algorithm

Plasma sheaths are non-neutral boundary layers that form adjacent to material surfaces due to the higher mobility of electrons relative to ions, establishing a strong electrostatic field normal to the boundary. Under steady-state (DC) conditions, sheath formation is governed by the Bohm criterion, which requires ions to enter the sheath with a velocity exceeding a critical value [1–3]. This time-independent limit provides a fundamental benchmark for more general time-dependent sheath models.

In many practical plasma applications, electrodes are often driven by radio-frequency (RF) sources, introducing explicit time dependence into the sheath dynamics through oscillatory boundary conditions. In RF-driven sheaths, the sheath potential ∅s(t), sheath width ds(t), and electric field E(x,t), vary periodically in time, leading to modulation of ion acceleration and energy deposition at the boundary. The characteristic ion response depends on the ratio of the RF frequency ω to the ion plasma frequency ωpi. For ω ≪ωpi ions respond quasi-statically to the instantaneous sheath electric field, whereas for ω~ωpi, ion motion becomes significant and a fully time-dependent treatment is required. Many analytical RF sheath models, therefore, rely on simplifying assumptions such as cold ions, negligible ion inertia, or time-averaged electric fields, which restrict their validity in regimes where finite ion temperature and pressure effects play an important role.

Motivated by these limitations, the present work develops a fully time-dependent fluid model for collision-less RF plasma sheaths [4], incorporating ion pressure effects and driven by a sinusoidal current source. The complete set of ion fluid equations is solved numerically using a flux-corrected transport (FCT) algorithm to ensure stability and accuracy. An equivalent circuit model is coupled self-consistently with the fluid equations to relate the instantaneous sheath potential to the sheath thickness. The present model provides an enhanced and self-consistent description of RF sheath dynamics, particularly in regimes where pressure effects cannot be overlooked

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