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Modeling of 1D DC Discharges Using Various Particle-in-Cell Schemes

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A common approach for modeling plasma dynamics in ion sources is the Particle-in-Cell (PIC) method. However, in the high-density, low-temperature, low-pressure plasmas typically found in ion sources, PIC simulations face significant challenges. Accurately resolving the Debye length and plasma frequency requires fine spatial and temporal resolution, along with sufficient particles per cell, leading to high computational cost. To alleviate these constraints, explicit and implicit energy-conserving PIC schemes, particularly those using non-uniform grids, have been proposed to enable lower-resolution simulations and achieve significant speedups in two- and three-dimensional models. While these approaches can reduce numerical demands, previous studies have shown that, for electrostatic cases, reductions in execution time may be offset by decreased accuracy due to larger cell sizes and lower particle counts, even when resolution is selectively relaxed in the quasi-neutral region while retaining fine resolution in the high-voltage sheath. Importantly, this trade-off has not yet been examined in the context of discharges sustained by electron emission from cathodes commonly used in ion sources. In this work, we apply energy-conserving explicit and implicit PIC schemes to a one-dimensional, low-pressure direct-current plasma discharge with a thermionic electron emission. We compare a standard momentum-conserving explicit scheme with lower-resolution variants of energy-conserving explicit and implicit approaches. Our results quantify the impact of reduced spatial and particle resolution on simulation accuracy and assess the viability of these schemes for predictive modeling in ion sources.

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