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Incorporating collisions and resistance into the transition from field emission to the space charge regime

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ABSTRACT

Advancements in microelectromechanical systems (MEMS) and microplasmas, particularly with respect to applications in combustion and biotechnology, motivate studies into microscale gas breakdown to enable safe system design and implementation. Breakdown at microscale deviates from that predicted by Paschen's law due to field emission—the stripping of electrons from the cathode in the presence of strong surface field—and follows the Fowler-Nordheim (FN) law. As injected current increases at this length scale, electrons accumulate in the gap and FN electron emission becomes space charge limited, leading to the Child-Langmuir (CL) law at vacuum and the Mott-Gurney (MG) law at high pressure. While theoretical studies link CL to FN and CL to MG, none links all three to simultaneously assess the importance of pressure and external resistance (perturbation) on electron emission. This study extends existing theory to elucidate the transition between these regimes as a function of applied voltage, gap distance, electron mobility, and external resistance, and in particular, derives asymptotic equations illustrating the transitions between the three. It also demonstrates the presence of a triple point, where one theoretically encounters FN, CL, and MG at once, and characterizes the importance of gap pressure and distance on these regimes, especially when MG dominates at non-vacuum pressures. The sensitivity of the triple point to external resistance, representative of the effects of perturbations in system parameters on electron emission, receives special attention.

KEYWORDS

Collisions, field emission, Fowler-Nordheim, Child-Langmuir, Mott-Gurney, external resistance