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Space-charge-limited flow in quantum regime[1]

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Space-charge-limited (SCL) flow has been an area of active research in the development of non-neutral plasma physics, high current diodes, high power microwave sources, vacuum microelectronics and sheath physics. According to the classical Child-Langmuir (CL) law for the planar diodes, the current density scales as 3/2's power of gap voltage and to the inverse squared power of gap spacing. In the past decade, there have been renewed interests in extending the classical CL law to multi-dimensional models both numerically and analytically. The study of SCL flow in quantum regime has also attracted considerable interests in the past 3 years [1-3]. With the recent advances in nanotechnology, electron beam with very high current density may be transported in a nano-scale gap with a relatively low gap voltage. In this new operating regime, where the electron wavelength is comparable or larger than the gap spacing, the quantum effects become important. In this talk, the quantum theory of CL law will be introduced to reveal that the classical CL law is enhanced by a large factor due to electron tunneling and exchange-correlation effects, and there is a new quantum scaling for the current density, which is proportional to the 1/2's power of gap voltage, and to the inverse fourth-power of gap spacing [1-2]. Quasi-2D and 3D models with finite emission area will be shown [3]. We will also show that the classical properties of the SCL flow such as bipolar flow, beam-loaded capacitance, transit time and noise will require a complete revision in the quantum regime. The implications of the emission law of Fowler-Nordheim in the presence of intense space charge over the nanometer scale will be discussed.

[1] L. K. Ang, T. J. T. Kwan, and Y. Y. Lau, "New Scaling of Child-Langmuir Law in the Quantum Regime," Phys. Rev. Lett. 91, 208303 (2003).
[2] L. K. Ang, Y. Y. Lau, and T. J. T. Kwan, "Simple Derivation of Quantum Scaling in Child-Langmuir law," IEEE Trans Plasma Sci. 32, 410 (2004).
[3] W. S. Koh, L. K. Ang, and T.J.T. Kwan, "Three-dimensional Child-Langmuir law for uniform hot electron emission," Phys. Plasmas 12, 053107 (2005).

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