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Modeling of Electronic Transport Phenomena in Semiconductor Nanodevices

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Development of novel semiconductor manufacturing processes and devices is aided by Technology CAD (TCAD) tools. These well established tools are gradually loosing their ability to accurately predict the electrical characteristics of nanoscale devices, as the process of down-scaling continues. This fact is prompting for enhancement of models presently used in TCAD and also for the introduction of new methods to meet the engineering demands. Semi-classical models are based on the moments of the Boltzmann equation. Using moment equations of higher order allows one to include hot-carrier effects more accurately and to reproduce similar results as obtained from much more time consuming and physically more accurate full-band Monte Carlo calculations. Incorporation of quantum corrections in semi-classical models can account for quantum effects to a certain extent.

A full quantum mechanical description is required if the active area of the nanodevice is on the order of the electron wave length. Carbon nanotube transistors can operate close to the quantum ballistic limit. Their electrical characteristics can be well predicted using a coherent quantum transport theory [1]. On the other hand, silicon-based FETs operated at room temperature are significantly affected by carrier scattering even for gate lengths as small as 5 nm. Accurate modeling of these devices requires a dissipative quantum description. The non-equilibrium Green's functions method addresses this problem in the most consistent and complete way. Due to its completeness, the method is computationally complex and is usually applied to one-dimensional problems and for a restricted set of scattering mechanisms only. An alternative approach which handles both quantum-mechanical effects and dissipative scattering effects is based on the Wigner function. Realistic scattering processes can be easily included through a Boltzmann-like collision operator [2]. All quantum transport models must be adapted for engineering applications, for which timely results are sometimes more valuable than accurate analyses [3]. It is still not clear which of the outlined quantum transport approaches will finally be integrated into TCAD environments. Its further success will depend on the ability to model quantum effects efficiently with reasonable accuracy.

[1] M. Pourfath, H. Kosina, B. Cheong, W. Park, and S. Selberherr; in Proc. European Solid-State Device Research Conf., Grenoble, 2005, pp. 541–544.

[2] H. Kosina, M. Nedjalkov, and S. Selberherr; J. Computational Electronics, vol. 2, no. 2–4, pp. 147–151, 2002.

[3] M. Duane; IEICE Trans.Electron., vol. E82-C, no. 6, pp. 976–982, 1999.