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DSMC versus WENO-BTE: A Double Gate MOSFET Example

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ABSTRACT

In modern highly integrated devices, a consistent description of the dynamics of carriers is essential for a deeper understanding of the observed transport properties. The semi-classical Boltzmann equation

$$\frac{\partial f}{\partial t} + \frac{1}{\hbar}\nabla_{\mathbf{k}}\varepsilon \cdot \nabla_{\mathbf{x}} f - \frac{q}{\hbar}\mathbf{E}\cdot\nabla_{\mathbf{k}} f = Q(f). \qquad (1)$$

coupled with the Poisson equation

$$\nabla_{\mathbf{x}}\left[\epsilon_r(\mathbf{x})\mathbf{E}\right] = -\frac{q}{\epsilon_0}\left[\rho(t,\mathbf{x}) - N_D(\mathbf{x})\right], \qquad (2)$$

provides a general theoretical framework for modeling electron transport. Moreover, time-dependent solutions of the Boltzmann equation contain all the information on the evolution of the carrier distribution. In Eq. (1), f represents the electron probability density function in phase space $\mathbf{k}$ at the physical location $\mathbf{x}$ and time t. $\mathbf{E}$ is the electric field, $Q(f)$ denotes the collision operator, which describes electron-phonon interactions and ε is the energy-band function. Physical constants $\hbar$ and q are the Planck constant divided by 2π and the positive electric charge, respectively. In Eq. (2), ϵ_0 is the dielectric constant in a vacuum, $\epsilon_r(\mathbf{x})$ labels the relative dielectric function depending on the material, $\rho(t,\mathbf{x})$ is the electron density, and $N_D(\mathbf{x})$ is the doping. Very recently, deterministic solvers to the Boltzmann-Poisson system (1)-(2) for two-dimensional devices were proposed [1]-[4]. These methods provide accurate results which, in general, agree well with those obtained from Monte Carlo simulations. In this paper, we consider a double gate MOSFET device [5] (Fig. 1) and compare numerical solutions, by means of the use of WENO schemes, of Eqs. (1)-(2) and results given by DSMC. Figs. 2-3 show charge density and electrical potential profiles, obtained by solving Eqs. (1)-(2), in the stationary state. Since the symmetric geometry and the boundary conditions, only the $y \geq 0$ domain is considered. In Figs. 4-6 we show a comparison between BTE solutions and DSMC. For a fixed value of y coordinate, we consider the charge density and the velocity. In our opinion, deterministic solutions might improve algorithms of DSMC, as, in particular, the charge assignment to the mesh, the treatment of the boundary conditions and the free flight duration, where well accepted rules do not exist.

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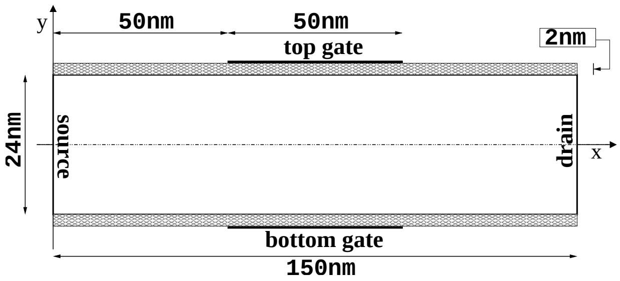

Fig. 1. A double gate MOSFET structure.

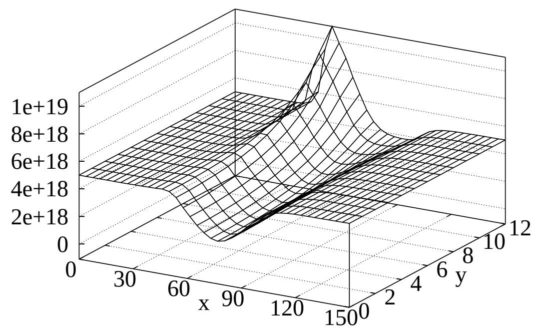

Fig. 2. Charge density. Units: x (nm), y (nm), density (cm^{-3}).

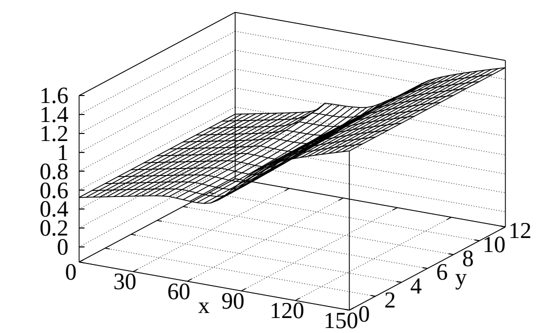

Fig. 3. Electric potential. Units: x (nm), y (nm), potential (Volt).

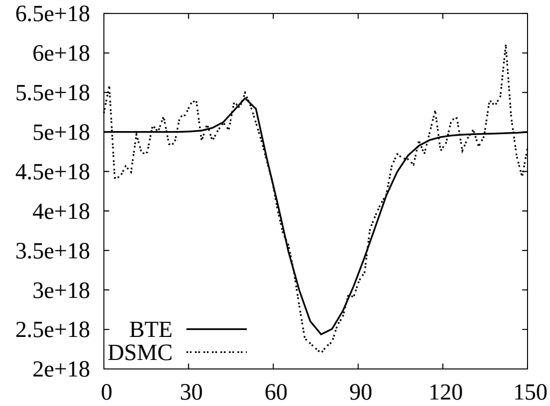

Fig. 4. Charge density at y = 6. Units: x (nm), density (cm^{-3}).

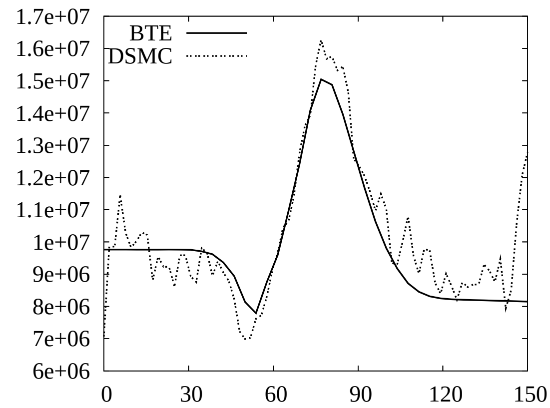

Fig. 5. x-component of the velocity at y = 6. Units: x (nm), velocity (cm/s).

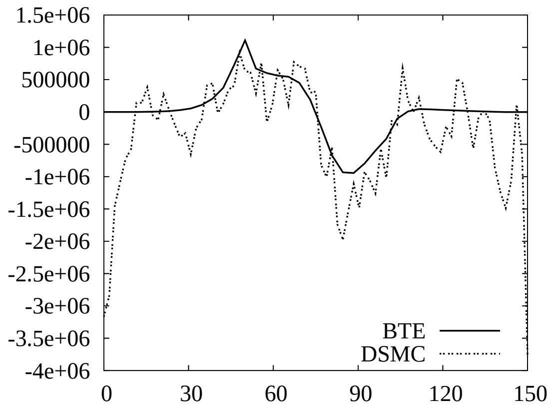

Fig. 6. y-component of the velocity at y = 6. Units: x (nm), velocity (cm/s).