Simulation of Tri-Gate MOSFET Using 3D Monte Carlo Method Based on the Quantum Boltzmann Equation

Jian Wang, Zhiliang Xia, Gang Du, Xiaoyan Liu, Ruqi Han
Institute of Microelectronics, Peking University, Beijing 100871, P.R.China
E-mail: Gang_Du@ime.pku.edu.cn

The progress in CMOS technologies has resulted in scaling down devices to nano-scale where quantum mechanical (QM) effects in carrier transportation become crucial for the device performance and simulation in three dimension of real space is necessary especially for the non-planar MOSFET such as double-gate MOSFET, tri-gate MOSFET and omega MOSFET. In this paper , a self-consistent full-band Monte Carlo method to solve quantum Boltzmann equation (QBE) three-dimensional both in real space and in K space is developed. The property of a 25nm tri-gate MOSFET is investigated by this method to verify the 3D MC program.

The quantum Boltzmann equation (QBE) obtained from quantum kinetics equation and Wigner distribution function can be used to describe the QM effect [1-4]. Comparing to semi-classical Boltzmann equation (BTE), quantum potential[2,4] and collision broadening [2,5,6] are two key QM effects in QBE that describe the quantum effect in real space and K space respectively.

In Monte Carlo method, the quantum potential correction gives an additional driving force while the carriers are free-flying and is self-consistently calculated every time step just like Poisson potential. As for collision broadening, the selection of the final energy after scattering has to be changed. The final energy is not only given by the initial energy and phonon energy as in the classical method. An additional random number is used to select the final state energy according to the joint spectral function. The joint spectral function for each scattering process is calculated and stored in a table to save CPU time.

The band structure of Si is obtained from empirical pseudo potential calculation. Four conduction bands and three valence bands are used. The acoustic and optical phonon scattering, the ionized impurity scattering, and the impact ionization scattering are also taken into account. PETSC[7] is employed as 3D Poisson equation solver.

The tri-gate MOSFET we used in the simulation is shown in Fig.1, with L=25nm, H=25nm, W=20nm, and gate-oxide thickness Tox=2nm. The channel p-doping is 10^{16} cm^{-3} and the source/drain n-doping is $10^{20}cm^{-3}$. Fig.2 plots the output characteristics with and without quantum effect (QM). The electron density distribution without QM along five sections of the channel is plotted in Fig.3 where the top-gate is on top of each color map, front-gate on the right and back gate on the left. To compare with classical case, Fig.4 shows the electron density distribution with QM along the same five sections. The quantum effects on the electron drift velocity are shown in Fig.5 and Fig.6. Both figures are plotted along the same L-W plane which cuts H-axis approximately in the middle. Fig.3-6 are all plotted when Vgs=Vds=1.0V.

Simulation results indicate that the quantum effects both in real space and momentum space are obvious in nano-scale device. The device I-V characters ,distributions of carrier density, and the drift velocity are all strongly affected by the quantum confinment in 3D.

References

[1]Gang Du, Xiaoyan Liu, Computational Electronics, 2004. IWCE-10 2004. Abstracts. Pages:186-187
[2]H. Haug, A.-p. Jauho *Quantum Kinetics in Transport and Optics of Semiconductors.* Springer 1998.
[3]W.Hansch *The Drift Diffusion Equation and Its Applications in MOSFET Modeling*. Springer 1991.
[4] Hideaki Tsuchiya and Tanroku Miyoshi. *IEICE TRANS.ELECTRON.* VOL.E82-C (1999) p.880.
[5]Antti-Pekka Jauho and Lino Reggiani. SSE Vol.31, No.3/4, pp.535-538, 1988
[6]Leonard F. Register and Karl Hess. Microelectronic Engineering Vol.47, 1999 p353
[7] S. Balay,et.al "PETSc Users Manual," Argonne National Lab., Argonne, IL, Tech. Rep. ANL-95/11—Revision.1.5,2002.

ISBN 3-901578-16-1

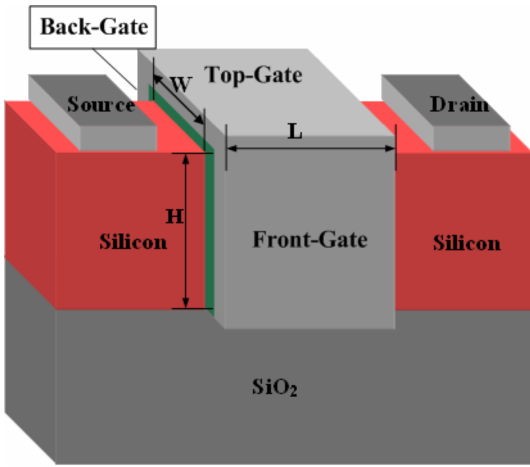

Fig. 1. Device Structure

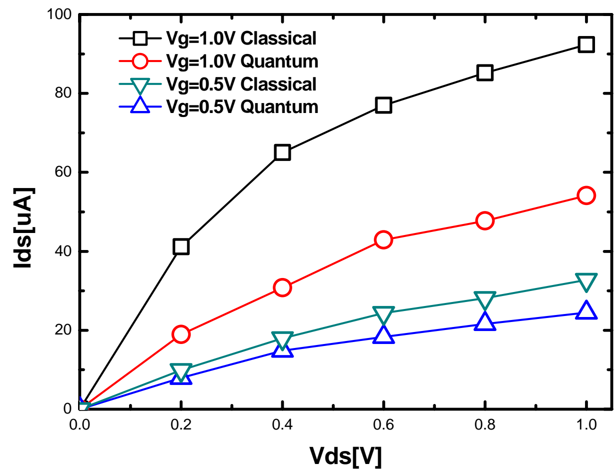

Fig. 2. Ids vs. Vds curves with and without QM

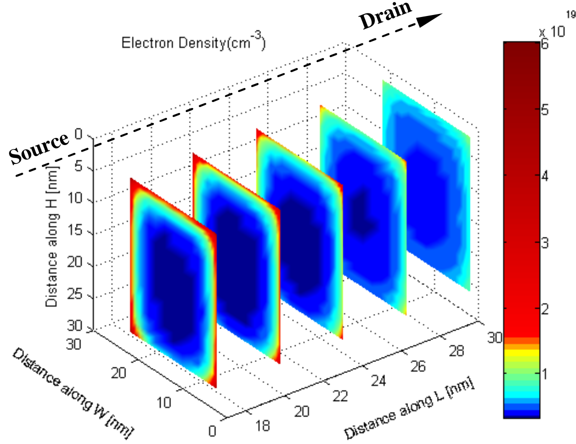

Fig. 3. Charge distribution without QM along five sections of the channel. The Source is on the left while Drain on the right.

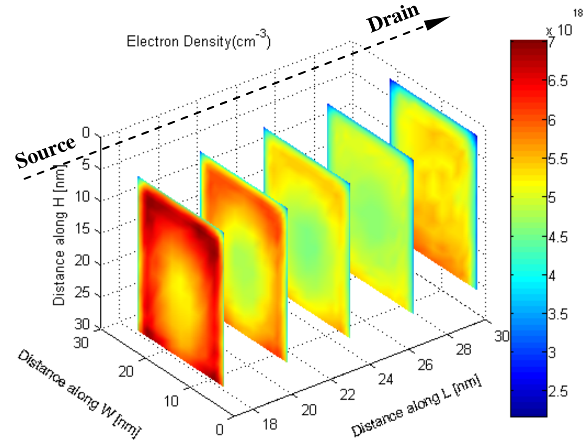

Fig. 4. Charge distribution with QM along the same five sections of the channel as in Fig.3

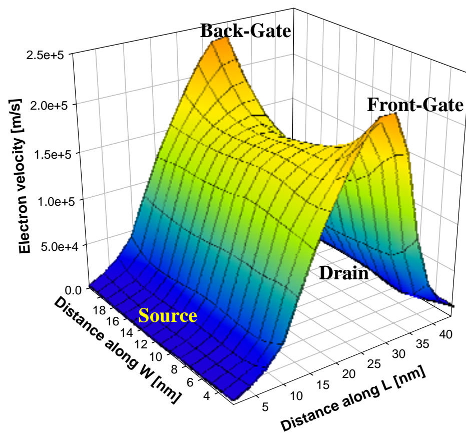

Fig. 5. Electron drift velocity without QM along L-W plane which cuts H-axis approximately in the middle

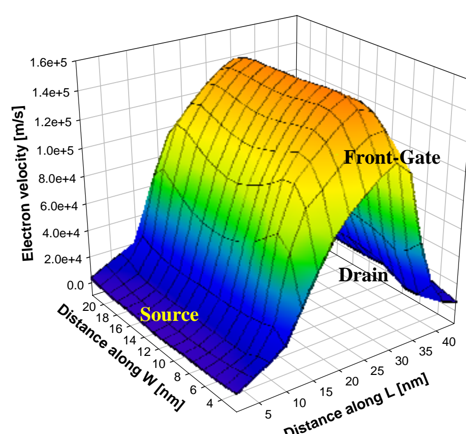

Fig. 6. Electron drift velocity with QM along the same L-W plane as in Fig.5.