Simulation of Si and Ge UTB MOSFETs Using Monte Carlo Method Based on the Quantum Boltzmann Equation

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

As the CMOS technology scaling down to sub 0.1um region, the quantum effects become obviously. From quantum kinetics equation and Wigner distribution function, the quantum Boltzmann equation (QBE) is investigated [1-3]. Comparing to semi-classical Boltzmann equation (BTE), quantum potential [1,3] and collision broadening [1,4,5] are two the key QM effects in QBE that describe the quantum effect in real space and momentum space respectively. In this paper the QBE is solved using self-consistent ensemble full band Monte Carlo (MC) method [6], and the Si and Ge UTB MOSFET is simulated use this method.QBE can be solved using full band MC method with the same procedure as BTE including the quantum potential and collision broadening. In MC method, the quantum potential correction gives the additional driven force during the carriers' free flight. The quantum potential is self-consistently calculated in every time steps just like Poisson's potential. As for collision broadening, the selection the final energy after scattering occurred has to be changed according to the joint spectral function. An additional random number is used to select the final states 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 structures of Si and Ge are obtained from empirical pseudopotential calculation including spin-orbit interactions [7]. Four conduction bands and three valence bands are used. The acoustic and optical phonon scattering, ionized impurity scattering, and impact ionization scattering are also considered [8,9]. The deformation potentials of Si and Ge used in the program are the same as in ref. [8,10]. A diffusive scattering model is used to implement the surface scattering effect. Fig.1 shows device structure of the Si UTB MOSFETs we used in the simulation, and the Si device parameters are showed in table 1, the threshold voltage of Si UTB nMOSFETs is 0.3V. Fig.2 plots the Output characteristics of different gate length Si UTB MOSFETs, using QBE the current increases as shown in fig.3. From fig.4 to fig.8 the quantum effects on the electron drift velocity, energy, the electron density, and the inversion layer charge are ploted. 2-D quantum effects can be found in these figures. Table 2 shows the structure parameter of Ge UTB MOSFETs. Fig.9 and fig.10 plot the simulation results of Ge device. The quantum effects in Ge device is weaker compare to Si device. Above results indicated that 2-D self consistent full band Monte Carlo method based on QBE can be used to investigate the 2-D quantum effects in sub-100nm semiconductor devices. This project is supported by the SFMSBRP (No. G2000036500). [1]H.Haug, A.-p.Jauho *Quantum Kinetics in Transport and Optics of Semiconductors*. Springer 1998. [2]W.Hansch *The Drift Diffusion Equation and Its Applications in MOSFET Modeling*. Springer 1991 [3]Hideaki Tsuchiya and Tanroku Miyoshi. *IEICE TRANS.ELECTRON*. VOL.E82-C (1999) p.880. [4]Antti-Pekka Jauho and Lino Reggiani. SSE Vol.31, No.3/4, pp.535-538, 1988 [5]Leonard F. Register and Karl Hess Microelectronic Engineering Vol.47, 1999 p353-355 [6]C. Jungemann, etc. IEICE Trans. Electron vol.e82-c. 1999, p.870 [7] J. R.Chelikowsky and Marvin L. Cohen, Phys. Rev. B 14, 556, 1976 [8]Carlo Jacoboni and Lino Reggiani, Review of Modern Physics, Vol.55, No.3, 1983, p645 [9]Phuong Hoa Nguyen, Karl R.Hofmann and Gernot Paasch, J.Appl.Phys. 94(1), 2003, p376 [10]F.M.Bufler, et.al, IEEE Trans. Electron Devices Vol.50, No.2, 2003, p418

A full journal publication of this work will be published in the Journal of Computational Electronics.

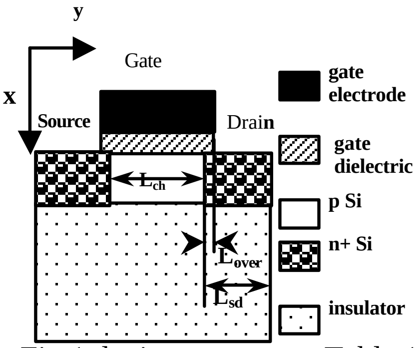

Fig.1 device structure

L_{ch} (nm)	T_{si} (nm)	N_{ch} (cm^{-3})	EOT (nm)	L_{sd} (nm)
45	11.25	$6.5x10^{17}$	1	25
65	16.25	$3x10^{17}$	1.2	35
90	22.5	$1.4x10^{17}$	1.5	45

S/D doping N_{SD}= $2x10^{20}cm^{-3}$, thickness of bulk insulator is 100nm, L_{over}= 5nm

Table 1 Si MOSFET parameters

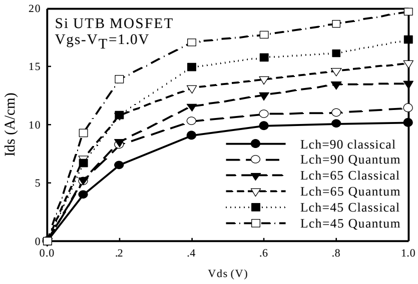

Fig.2 Ids vs Vds curves of different channel length Si UTB MOSFET

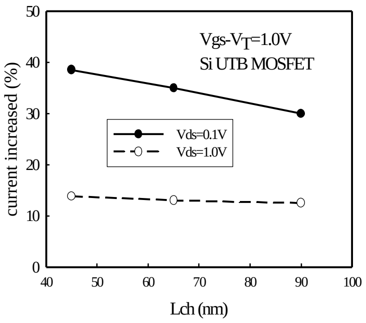

Fig.3 current increasing percent with quantum effect

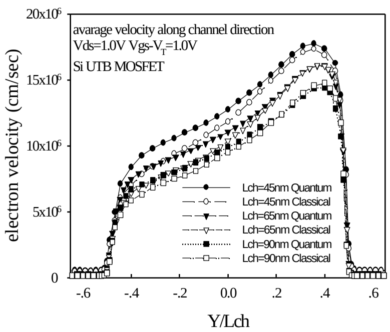

Fig.4 average electron drift velocity along channel direction

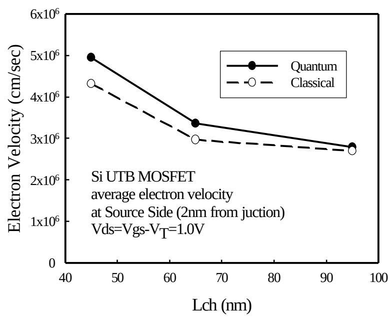

Fig.5 quantum effect on the electron velocity at source side

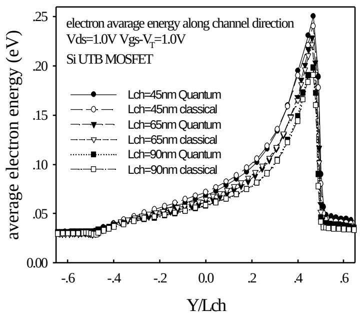

Fig.6 average electron energy distribution

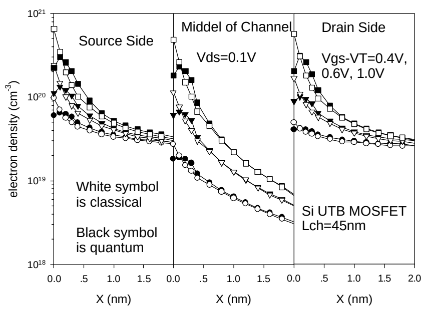

Fig.7 electron density distribution in the direction vertical to channel

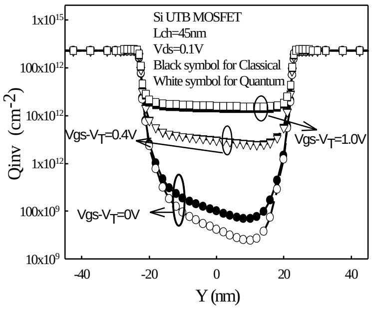

Fig.8 Qinv distribution in 45nm Si UTB MOSFET

L_{ch} (nm)	N_{ch} (cm^{-3})
45	$1x10^{17}$
65	$7x10^{16}$
90	$3x10^{16}$

S/D doping N_{SD}= $5x10^{19}cm^{-3}$, other parameter is same as Si

Table 2 Ge UTB MOSFET structure parameters

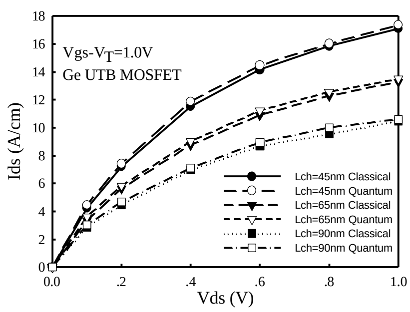

Fig.9 Ids vs Vds curves of Ge UTB MOSFETs

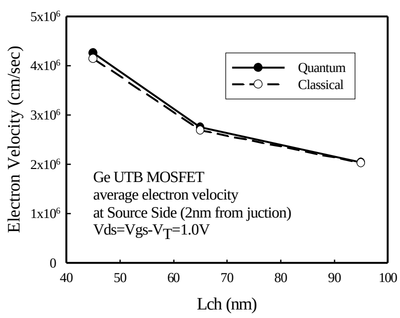

Fig.10 electron velocity at source side of Ge MOSFETs

A full journal publication of this work will be published in the Journal of Computational Electronics.