11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Monte Carlo Simulation of Double Gate MOSFET Including Multi Sub-Band Description

J. Saint-Martin, A. Bournel, F. Monsef, C. Chassat and P. Dollfus
Institut d'Electronique Fondamentale, CNRS UMR 8622, Université Paris Sud, Bât. 220, F 91405 Orsay cedex, France,
E-mail: jerome.saint-martin@ief.u-psud.fr

INTRODUCTION

Double gate (DG) structures are promising architectures likely to overcome short channel effects in nanometer scaled MOSFET. In sub 50 nm MOSFETs, T_{Si} (Si body thickness) should be typically less than 10 nm to obtain good performances in both off and on states [1]. In order to accurately describe these transistors, quantum effects in the transverse direction and also quasi-ballistic carrier transports need to be taken into account.

MODEL

Inspired by the mode-space approach of quantum transport [2] and the MC technique developed in ref. [3], our Monte Carlo simulations of DG MOSFET are self consistently coupled with 1D Schrödinger equation (cf. Fig 1 and Fig 2). Then, the x-axis, along which the carrier movement is supposed to be semi-classical, is separated from the z axis along which the energy is quantized (energies E_n and wavefunctions $\xi_n(z)$ associated with the sub-bands 'n').

2D scattering mechanisms included in the simulation are bulk phonon and impurity scatterings, taking non parabolic and ellipsoidal band structures into account [4]. Roughness scattering treatment is underway and is not included in these preliminary results.

RESULTS

The simulated 15 nm-long DGMOS device is described in Fig. 1. Fig. 3 presents the evolution of the quantized energies in the structures and the square of wave function associated with the first sub-band. In accordance with the mode space approach [2], the profile of this wavefunction does not significantly depend on x, even in the high electric field region (drain end). Fig. 4 clearly indicates that the electrons are moved away from the Si/SiO_2 interface due to quantum repulsion in the whole structure.

As the velocities in this 15 nm long channel, shown in Fig. 5, are much higher than the stationary saturation velocity (about 10^5 m/s), the carrier transport is far from equilibrium. Moreover, Fig. 5 exhibits hot electron transfer from the lowest energy sub-band to higher sub-bands, in particular near the drain region. As a consequence, the sub-band occupation in the channel strongly differs from that obtained with a 1D Schrödinger-Poisson algorithm in which equilibrium distribution is assumed.

At last, Fig. 6 presents the drain current as a function of the gate voltage for both classical (3Dk) and multi sub-band (2Dk) simulations. The current is only softly modified by quantization effects.

CONCLUSION

Multi sub-band description allows us to properly include the effects of quasi-ballistic transport and scattering on sub-band occupancy in nanoscale devices. With the price of a large increase of computation time, it gives a more accurate description of density profile and carrier transport than quantum correction approach. A detailed investigation of transport, ballisticity and I-V characteristics including the roughness influence will be presented at the conference.

REFERENCES

[1] Saint-Martin J. et al., *Comparison of multiple-gate MOSFET architectures using Monte Carlo simulation*, Solid State Electronics, in Press.

[2] Venugopal R. et al., *Simulating Quantum Transport in Nanoscale MOSFETs: Real vs. Mode Space Approaches*, J. Appl. Phys. **92**, 3730 (2002).

[3] Fischetti M.V., Laux S.E. *Monte Carlo study of electron transport in silicon inversion layers*, Phys. Rev. B **48**, 2244 (1993).

[4] Monsef F. et al., *Electron transport in Si/SiGe modulation-doped heterostructures using Monte Carlo simulation*, J. Appl Phys. **95**, 35870 (2004).

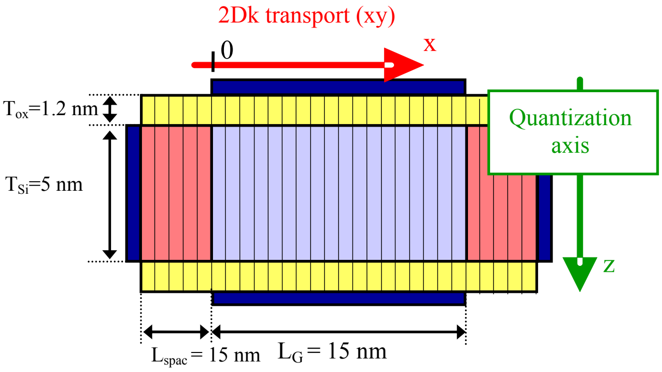

Fig. 1. Schematic of DGMOS structure

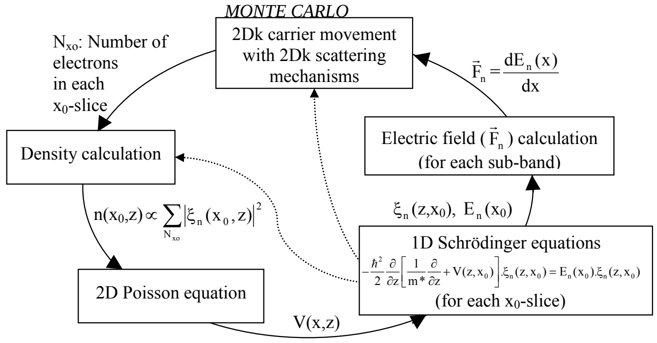

Fig. 2. Multi sub-band Monte-Carlo algorithm

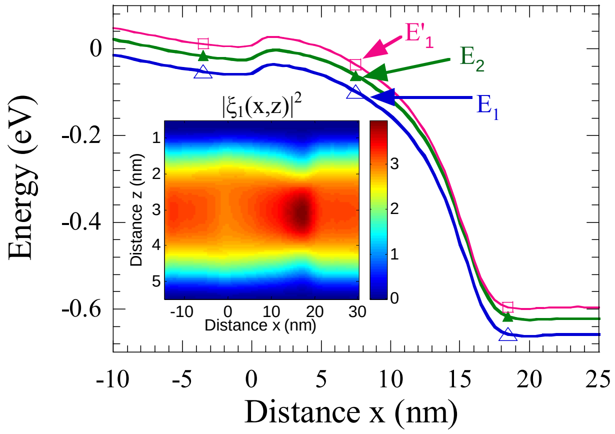

Fig. 3. Quantized energy evolutions along x axis. Inset: 2D cartography of square wavefunction of the first sub-band. NB. : nonprime and prime sub-bands have a quantization mass of $0.916.m_0$ and $0.19.m_0$, respectively

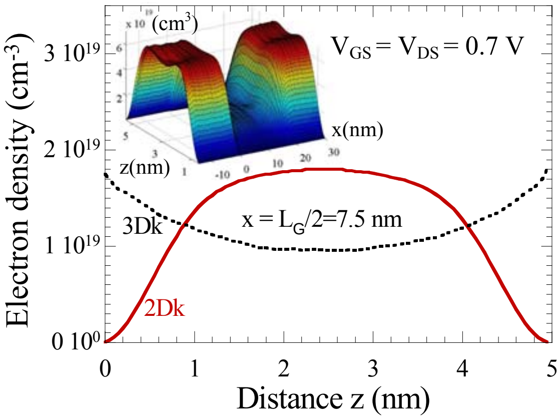

Fig. 4. Electron density versus distance z by including 2Dk (continuous lines) or not 3Dk (dashed lines) quantization effects. Inset: 2D cartography of electron density

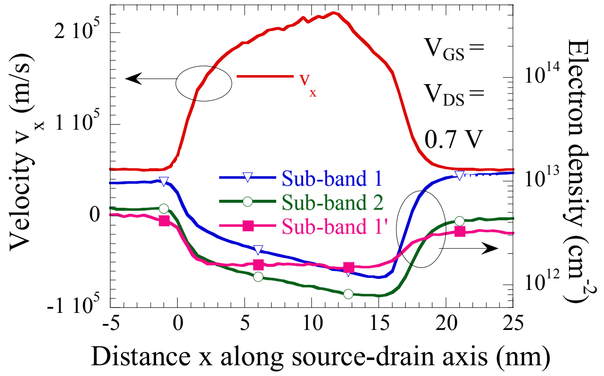

Fig. 5. Average velocity v_x and sheet density of first sub-bands versus distance x. N.B: E_1'>E_2>E_1.

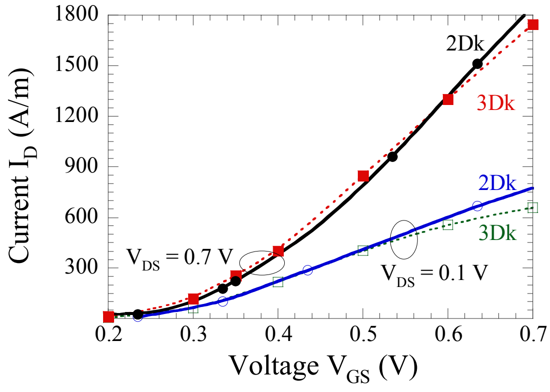

Fig. 6. Drain current I_D versus Gate voltage V_{GS} by including 2Dk (continuous lines) or not 3Dk (dashed lines) quantization effects.