Simulation of a double-gate MOSFET by a non parabolic energy-transport subband model based on MEP including surface roughness scattering

V. D. Camiola[1], G. Mascali[2], and V. Romano[1]

[1] University of Catania, Italy camiola@dmi.unict.it, romano@dmi.unict.it
[2] University of Calabria, and INFN-Gruppo collegato di Cosenza, Italy mascali@unical.it

Summary. A nanoscale double-gate MOSFET is simulated by using a model based on the maximum entropy principle (MEP) by including the surface scattering roughness. The influence of this latter on the electrical performace of the device is discussed.

1 Mathematical model and simulations

The main aim of the paper is to simulate the nanoscale silicon double gate MOSFET (hereafter DG-MOSFET) shown in Fig. 1. The length of the diode is L_x= 40 nm, the width of the silicon layer is $L_z = 8$ nm and the oxide thickness is t_{ox} = 1 nm. The n^+ regions are 10 nm long. The doping in the n^+ regions is $N_D(x) = N_D^+ = 10^{20}$ cm^{-3} and in the n region is $N_D(x) = N_D^- = 10^{15}$ cm^{-3}, with a regularization at the two junctions by a hyperbolic tangent profile.

Due to the symmetries and dimensions of the device, the transport is, within a good approximation, one dimensional and along the longitudinal direction with respect the two oxide layers, while the electrons are quantized in the transversal direction. Six equivalent valleys are considered with a single effective mass $m^* = 0.32m_e$, m_e being the free electron mass.

Since the longitudinal length is of the order of a few tents of nanometer, the electrons as waves achieve equilibrium along the confining direction in a time which is much shorter than the typical transport time. Therefore we adopt a quasi-static description along the confining direction by a coupled Schrödinger-Poisson system which leads to a subband decomposition, while the transport along the longitudinal direction is described by a semiclassical Boltzmann equation for each subband.

Numerical integration of the Boltzmann-Schrödinger-Poisson system is very expensive, from a computational point of view, for computer aided design (CAD) purposes (see references quoted in [1, 2]) In [1] we have formulated an energy transport model for the charge transport in the subbands by including the non parabolicity effect through the Kane dispersion relation. The model has been obtained, under a suitable diffusion scaling, from the Boltzmann equations by using the moment method and closing the moment equations with the Maximum Entropy Principle (MEP). Scatterings of electrons with acoustic and non polar optical phonons are taken into account. The parabolic subband case has been treated and simulated in [2].

The main aim of the present paper is to include also the surface roughness scattering in which electrons scatter off the boundaries of the confining potential. The rate of this scattering is higher when the gate voltage increases and the width of the silicon layer is below ten nm and therefore comparable with the fluctuations in the oxide thickness. We want to assess the relevance of this scattering on the electric performance of the device after proposing an appropriate numerical scheme for the MEP energy transport-Schrödinger-Poisson system. In the Figures we report the results obtained by including the nonparabolicity effects but without surface roughness scattering. These preliminary simulations are rather encouraging and we are currently working upon the inclusion of the scattering at the surface.

Acknowledgement. V.D.C. and V. R. acknowledge the financial support by the P.R.I.N. project 2010 Kinetic and macroscopic models for particle transport in gases and semiconductors: analytical and computational aspects and by P.R.A. University of Catania. G. M. acknowledges the financial support by P.R.A., University of Calabria.

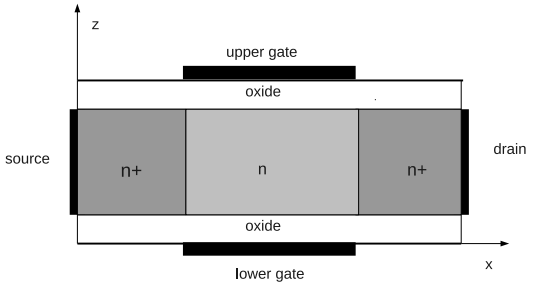

Fig. 1. Simulated DG-MOSFET

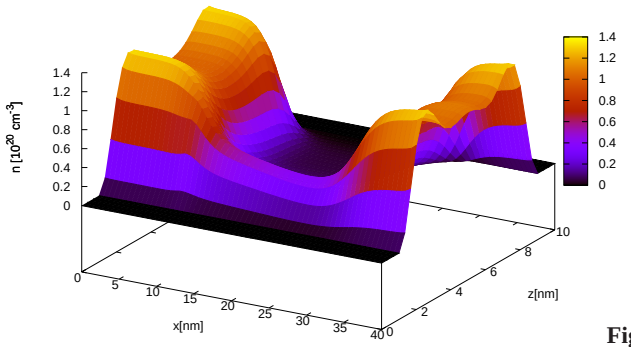

Fig. 2. Density in the case source-drain voltage $V_D = 0.5$ V and both gate voltages equal to -3 V

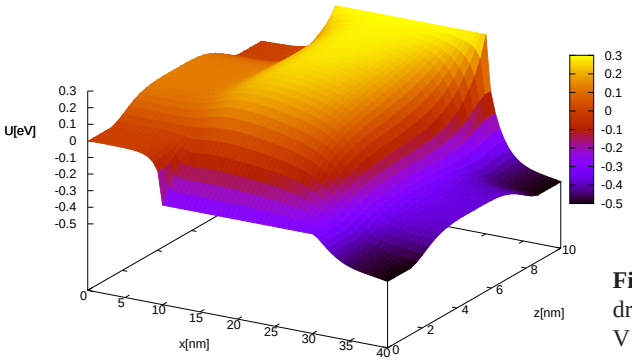

Fig. 3. Electrostatic potential energy in the same case as in Fig. 2

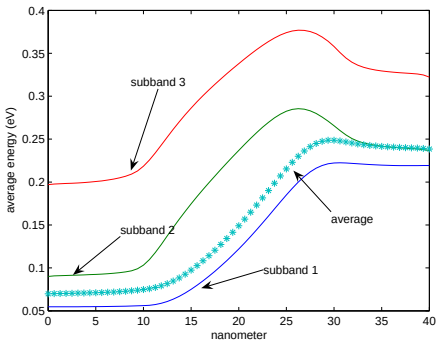

Fig. 4. Energies in the first three subbands in the case $V_D = 0.5$ V and lower gate voltage $V_{gl} = -3$ V, upper gate voltage $V_{gu} = 3$ V

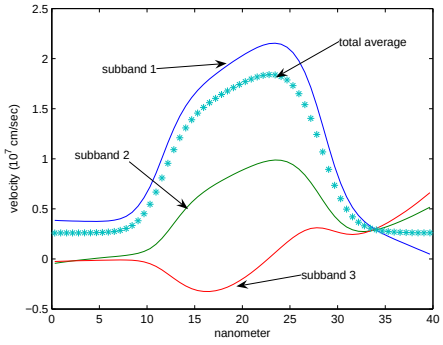

Fig. 5. Velocities in the first three subbands in the same case as in Fig. 4

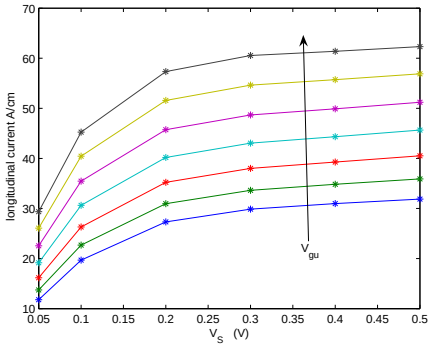

Fig. 6. Longitudinal mean current (A/cm) versus the source-drain voltage V_D with $V_{gl} = -3$ V and V_{gu} ranging from - 3 V to +3 V according to the arrow

References

1. G. Mascali, and V. Romano, A non parabolic hydrodynamical subband model for semiconductors based on the maximum entropy principle. *Mathematical and Computer Modelling* 55: 1003, 2012
2. V. D. Camiola, G. Mascali, and V. Romano, Numerical simulation of a double-gate MOSFET with a subband model for semiconductors based on the maximum entropy principle. *Continuum Mech. Thermodyn.* (2012) (already available online).