Edited by S. Selberherr, H. Stippel, E. Strasser – September 1993

Monte Carlo MOSFET Simulator Including Inversion Layer Quantization

J. Voves

Department of Microelectronics, Faculty of Electrical Engineering,
The Czech Technical University of Prague
Technickà 2, CS-16627 Praha 6, CZECH REPUBLIC

Abstract

A two-dimensional ensemble Monte Carlo Si-n-MOSFET simulator, considering two-dimensional electron gas behaviour in inversion layer, is presented. Description of inversion layer quantization is solved in the new complex way. Standard bulk Monte Carlo transport model is switched to the two-dimensional electron gas model always when electron reaches the quantized region. Electron energy profiles along the MOSFET channel are studied. Comparison with experimental results, measured on the short channel MOSFET test structures is performed.

1. Introduction

In the latest most advanced Monte Carlo MOSFET simulators [1,2] inversion layer quantization effects are not treated. Until now the problem of the electron transport in the MOSFET inversion layer has been solved only by the separate quasi-two-dimensional Monte Carlo simulation with uniform inversion layer thickness [3].

2. Present model

The present simulator solves this problem in a new complex way. Initial conditions are calculated by "drift -diffused" two-dimensional simulator PISCES-2B. Appropriate

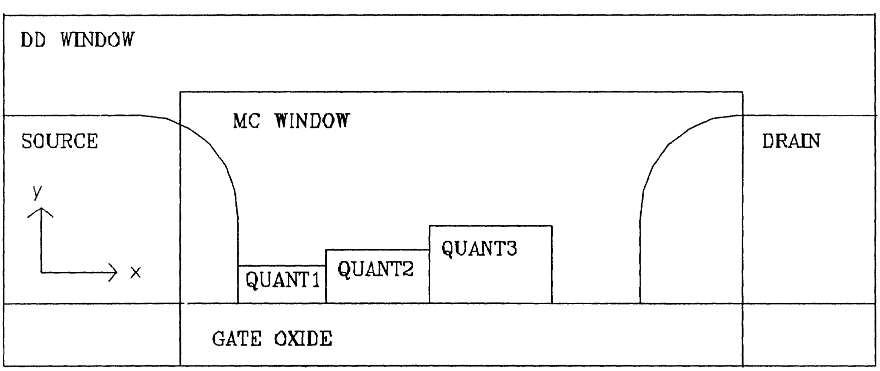

Fig.1 Windows for "drift-diffused" (DD) and Monte Carlo (MC) simulation and quantum regions (QUANT1-3).

window is chosen for Monte Carlo simulation. Quantized region near to Si-SiO_2 interface is divided into several parts as shown in Fig.1. Subband energy levels are calculated using actual values of inversion and depletion layer charges. These levels are schematically drawn in Fig.2. Standard bulk Monte Carlo transport model is switched to two-dimensional electron gas model always when electron reaches the quantized region. Surface roughness, interface oxide charge, intravalley phonon and intervalley phonon scattering rates are calculated using following assumptions: 1/ Only three lowest subbands E_0, $E_{0'}$ and E_1 are considered in the Hartree approximation. 2/ Energies E_0 and $E_{0'}$ subbands are assumed to be equal. 3/ No dependence of quantization on the lateral electric field is supposed [4].

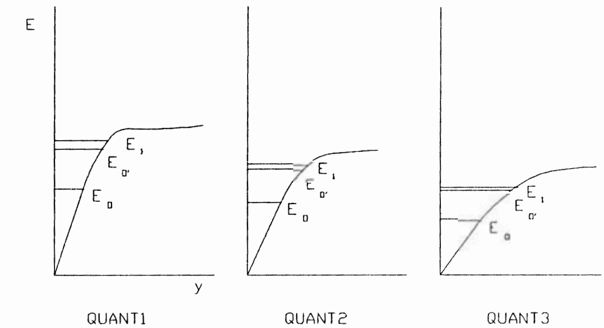

Fig.2 Schematic silicon conduction band profiles and three lowest subband energy levels E_0, E_1 and $E_{0'}$ in different quantized inversion layer regions QUANT1-3.

3. Simulation results

Higher electron mobility in the MOSFET inversion layer due to 2-D electron gas transport is observed especially for smaller drain bias. Comparison of corresponding electron energy profiles is depicted in Fig.3. 2D electron energy profiles in the MOSFET channel region are analyzed with respect to the drain junction avalanche breakdown and hot electron emission into the gate oxide [5]. Fig.4 gives an example of this profile with energy peaks at source and drain junctions. Comparison with experimental results, measured on the short channel MOSFET test structures is performed. Better agreement of calculated and

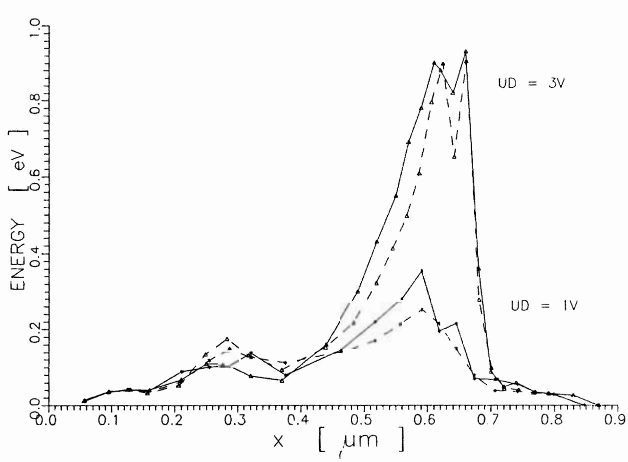

Fig.3 Electron energy profiles in DDD1 NMOSFET with 1um gate length for bias $V_D = 1V$ and 3V, $V_G = 1.46V$ with inclusion of quantum effects (solid) and without them (hatched).

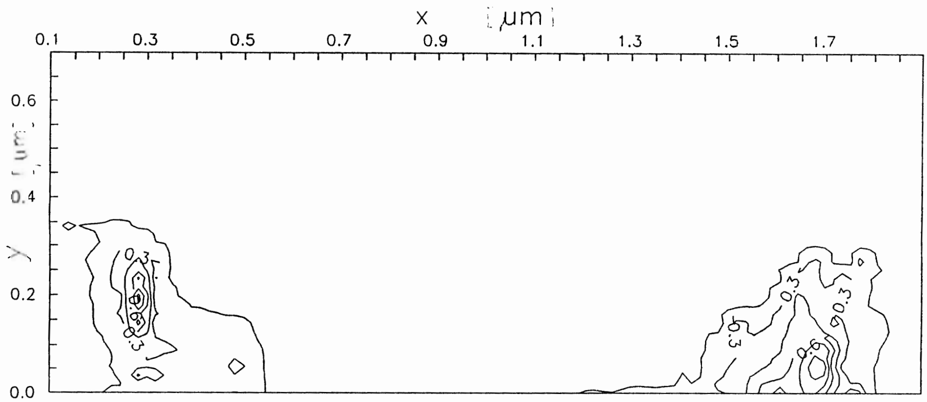

Fig.4 Equienergetical lines of electrons in DDD1 NMOSFET for bias V_D=3V, V_G=2.26V and gate length 2 um.

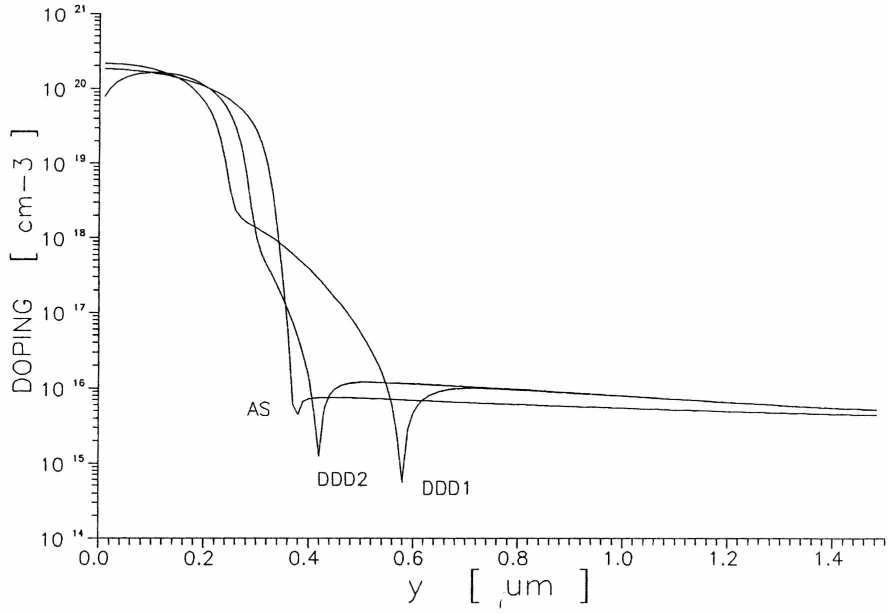

Fig.5 Doping profiles of S/D regions for different NMOSFET modifications (As drain, DDD1, DDD2 "double diffused drain").

measured data by inclusion of inversion layer quantization is observed.
The MC Simulator is used in MOS IC process evaluation. Transistors fabricated by standard As-drain NMOS technology are compared with two modifications of DDD ("double diffused drain") MOSFET. Source/drain regions concentration profiles in the transversal 1-D section are shown in Fig.5. Corresponding average electron energy

profiles along the channel are drawn in Fig.6 for gate bias 2.26V and drain bias 3V. Noticeable lowering of energy peak for DDD1 structure is evident.

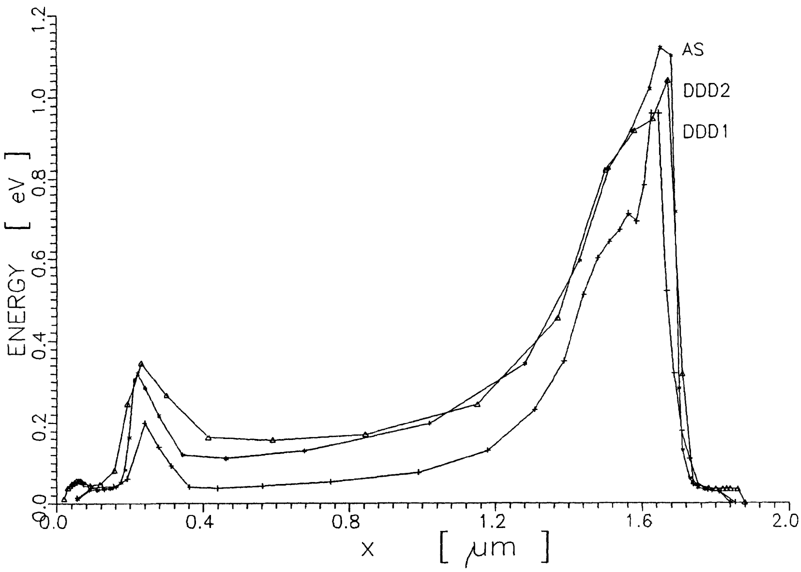

Fig.6 Electron energy profiles in As, DDD1 and DDD2 NMOSFET for bias $V_D=3V$, $V_G=2.26V$ and gate length 2 um.

4. Conclusions

Inclusion of inversion layer quantization into MC MOSFET Simulation results in the significant increasing of electron energy in the inversion layer comparable to differences induced by technological modifications of drain impurity profiles. Effect is more evident for lower drain voltages as can be expected.

References:

[1] F. Venturi, E. Sangiorgi, R. Brunetti, W. Quade, C. Jacoboni, B. Rico: Monte Carlo Simulation of High Energy Electrons and Holes in Si-n-MOSFET's, IEEE Trans. on CAD, vol. 10, pp. 1276-1285, (1991)

[2] M. V. Fischetti, S. E. Laux: Monte Carlo Simulation of Transport in Technologically Significant Semiconductors of the Diamond and Zinc-Blende Structures-Part II: Submicrometer MOSFET's, IEEE Trans on El. Dev., vol. 38, pp. 650-660, (1991)

[3] Ch. Hao, J. Zimmermann, M. Charef, R. Fauquembergue, E. Constant: Monte Carlo Study of Two-Dimensional Electron Gas Transport in Si-MOS Devices, Solid-St. El., vol. 28, pp. 733-740, (1985)

[4] J. Voves: Inversion Layer Quantization in Monte Carlo MOSFET Simulation, 13th Gen.Conf.Cond.Matter Div.EPS, Regensburg, (1993)

[5] J. Voves, J. Veselý: MOSFET Gate Current Modelling Using Monte Carlo Method, ESSDERC 88, pp.791-794, Montpellier, (1988)