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Quantum Ensemble Monte Carlo Simulation of Silicon-Based Nanodevices

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ABSTRACT

A Quantum Ensemble Monte Carlo (QEMC) simulator is used to calculate electrical characteristics and transient response of actual nanotransistors: both sub-50nm CMOS N-MOSFETs and ultrathin double gate SOI transistors, have been deeply studied. Doping profiles and oxide thickness have been selected to cope with the available specifications of the ITRS Roadmap and have been tuned in order to comply with the specification for the maximum leakage drain current in OFF state. The Quantum Ensemble Monte Carlo simulator QEMC has been used to self-consistently solve the Boltzmann Transport and Poisson equations in actual devices. Quantum effects are included through a multivalley version of the Effective Conduction Band Edge (ECBE) model, and new approaches for phonon and surface roughness scattering have been developed to include the effects of carrier quantization.).

MULTI-VALLEY EFFECTIVE CONDUCTION BAND EDGE METHOD

It is possible to include quantum effects in nano-transistors without solving the Schrödinger equation by adding a correction term to the electrostatic potential [1-2]. Thus, it is possible to reproduce the carrier density given by the full quantum solution. In drift-diffusion simulations Density Gradient (DG) model [1] has been widely used. However, this correction cannot be implemented easily in Monte Carlo simulations due to the fact that the driving force depends on the third derivative of the electron concentration which is a very noisy magnitude. To avoid this problem, the quantum correction should be expressed in terms of the electrostatic potential. The Effective Conduction Band Edge (ECBE) method explodes this idea[2]. Starting from the DG and assuming an exponential relation between the electron concentration and the potential, the effective potential can be evaluated. Independent calculations for each valley are included to avoid mass fitting. The developed simulator is 2D real-space and 3D k-space where time is also considered as an independent variable to perform transient simulations. Phonon, surface roughness and Coulomb scattering are taken into account. Surface roughness scattering has been implemented using a three dimensional version of the model proposed by Gamiz et al [3], for two-dimensional electron gases. In addition, to take into account the effect of quantization on phonon scattering, a new phonon scattering model has been developed. Figure 1 compares the electron mobility obtained with a one-particle Monte Carlo simulator (where quantum effects are taking into account by solving Schroedinger equation) and the electron mobility obtained with the QEMC simulator, for a DGSOI device (T_{Si}=12nm).

SIMULATION RESULTS

Different structures have been studied with the QEMC simulator developed here. Figure 2 shows the results for a 25nm channel length MOSFET with HALO implants. Oxide thickness was considered to be 8.9 nm, and the doping profiles (shown in Figure 2-b) were selected to reduce short channel effects. Fig.2-c and 2-d show the averaged electron velocity along the channel and the averaged drift electric field along the channel. Fig.2-a shows the actual carrier distribution in the device when quantum corrections are taken into account. As can be observed, the maximum of the distribution is not anymore at the interface and its position corresponds to the predicted by the solution of the Schrödinger equation. Fig. 3 shows the results for a DGSOI transistor. The silicon thickness was considered to be 7nm (a-c) and 12nm in Fig.3-b. The channel length is 25nm, and the oxide thickness

T_{ox}=8.9nm for the two gates. Fig.3-a shows the electron distribution when the two gates are biased at V_{GS}=1V, and V_{DS}=0.5 V. Note once more how carriers are push out of the interfaces because of quantum effects. Fig.3-c shows that quantization breaks down the degeneracy of the Si conduction band minima, and as a consequence the population of the valleys with longitudinal effective mass perpendicular to the interface (Valley 1) is higher than the population of the valleys showing the transverse effective mass perpendicular to the interface. Finally, this simulator allows us to calculate the electrical characteristics of these nanodevices both in transient and stationary regimes (Fig.4).

CONCLUSIONS

A quantum corrected QEMC simulator using the multi-valley version of the ECBE method has been presented. This method can be used in MC studies due to the fact that the problems derived from the noisy electron distribution are avoided. This simulator allows us to study actual devices, and evaluate their electrical characteristics (both transient and stationary responses).

ACKNOWLEDGMENTS

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REFERENCES

[1] M. G. Ancona G. J. Iafrate, *Quantum Correction to the equation of state of an electron gas in a semiconductor* Phys. Rev. B, **39**,9536 (1989)
[2] TW Tang B Wu, *Quantum correction for the Monte Carlo simulation via the effective conduction-band edge equation* Semicond. Sci. Technol., **19**, 54 (2004)
[3] F. Gámiz, et al., *Surface Roughness at the Si-SiO2 Interfaces in Fully Depleted Silicon-On-Insulator Inversion Layers* J. Appl. Phys., **86**, 6854 (1999)

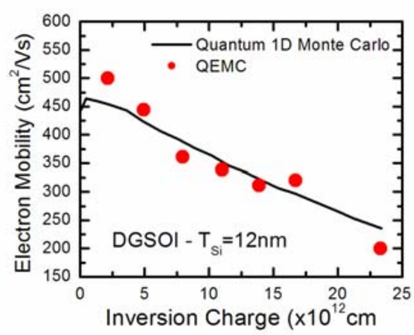

Fig.1: Comparison of the electron mobility in a DGSOI MOSFET evaluated using a one-particle Monte Carlo simulator and the QEMC simulator.

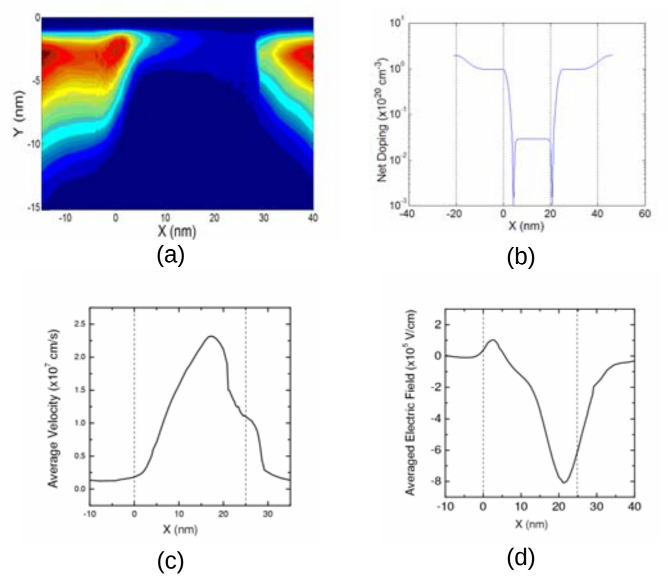

Fig.2: QEMC simulation of a 25-nm NMOSFET with HALO implants: a) charge distribution with V_{GS}=V_{DS}=1V; b) Net doping profile along the channel; c,d) Averaged drift velocity and averaged electric field along the channel.

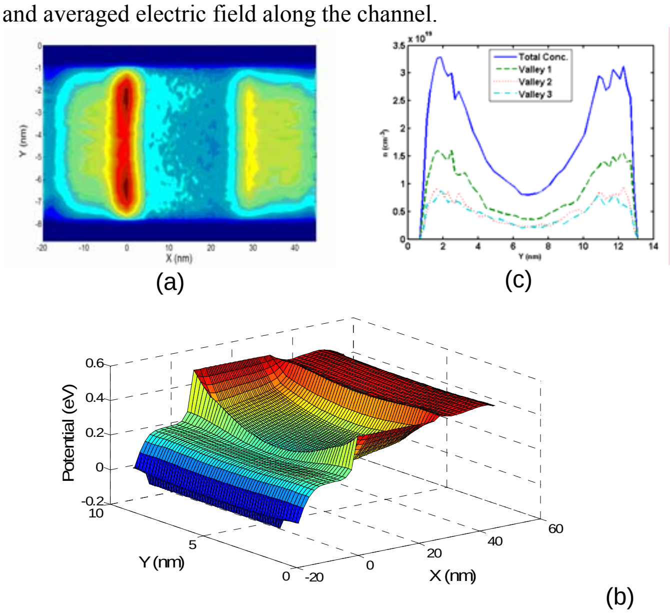

Fig.3: QEMC simulation of a 25-nm DGSOI MOSFET: Electron distribution (a) and potential distribution (b) with V_{GS}=1V, V_{DS}=0.5V; c) Total electron distribution along the direction perpendicular at the interfaces, and contribution of each valley.

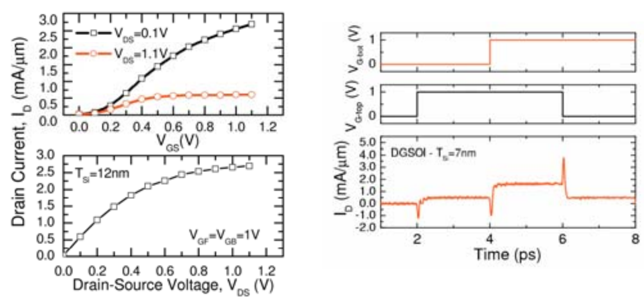

Fig.4: (a) Calculated I-V characteristics of a 25nm channel length DGSOI MOSFET. (b) Transient simulation.