A Compact Quantum Model of Nanoscale Double-Gate MOSFET for RF and Noise Simulations

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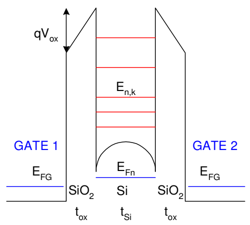
Abstract In this paper, we present a new analytical model for RF and microwave noise model of nanoscale double-gate MOSFET. The model is based on a compact model for charge quantisation within the channel and it includes overshoot velocity effects. RF and noise performances are calculated using active transmission line method. A comparison between classical and quantum charge control, and between drift-diffusion and hydrodynamic models is done.

MOTIVATION

Double-gate (DG) MOSFET transistors are considered to be a very attractive option to improve the performance of CMOS devices and overcome some of the difficulties encountered in the downscaling of MOSFETs into the sub-50 nanometer gate length regime. Due to scaling, the silicon thickness is ultra-thin and quantum confinement must be included in the models. Then, a self consistent solution of Schrödinger-Poisson equations is needed. We obtain a new compact charge control model including quantum effects whose explicit formulation is similar to classical charge control. Velocity overshoot is included in the model using a one-dimensional energy-balance model.



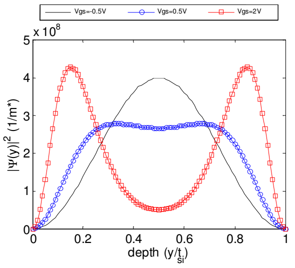


Fig. 1. Lowest subband eigenfunction

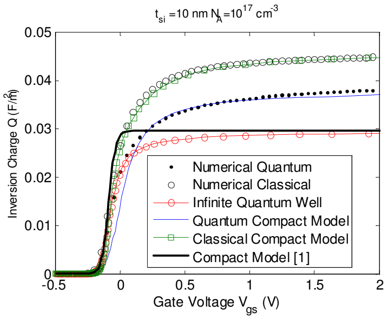


Fig. 2. Comparison of inversion capacitance as a function of gate voltage between the classical and quantum models (t_{si}=10 nm, $N_A=10^{17}$cm^{-3}).

QUANTUM CHARGE CONTROL

In order to calculate the charge densities from an explicit expression of the applied bias, we use the following equation:

$$Q=2C_{ox}\left(-\frac{2C_{ox}\beta^2}{Q_{Dep}}+\sqrt{\left(\frac{2C_{ox}\beta^2}{Q_{Dep}}\right)^2+4\beta^2\log^2\left[1+e^{\frac{V_{GS}-V_{th}+\Delta V_{th}-V}{2\beta}}\right]}\right)$$

In quantum case, the same expression can be used if a corrected oxide capacitance is used:

$$C_{ox}^{*}=\frac{C_{ox}}{1+C_{ox}\dfrac{y_I}{\varepsilon_{si}}}$$

A simple relationship between inversion centroid y_I and inversion charge obtained fitting numerical simulation results is given by:

$$\frac{1}{y_I}=\frac{1}{a+b\cdot t_{si}}+\frac{1}{y_{I0}}\left(\frac{N_I}{N_{I0}}\right)^n$$

A first iteration of charge using the compact model is used to calculate the corrected oxide capacitance, and then, using (2) we obtain the inversion charge replacing C_{ox} by $C_{ox}{}^{*}$.

Comparison of this model with numerical classical and quantum simulations are performed using SCHRED with good agreement in the two cases.

This new unified compact model has the same explicit expression for classical and quantum-effect model but using different threshold voltages (see fig.2) and effective oxide capacitance.

DC CURRENT

Hydrodynamic transport model

In extremely short channel DG MOSFET the channel is quasi-ballistic, thus an important overshoot velocity is expected. Using a simplified energy-balance model, the electron mobility is a function of the electron temperature related to the average energy of the carriers. The electron temperature T_e is governed by the following equation:

$$\frac{dT_e}{dx}+\frac{T_e-T_0}{\lambda_w}=-\frac{q}{2k}E_x(x)$$

where the energy-relaxation length is defined as $\lambda_w=2v_{sat}\tau_w$, being τ_w the energy relaxation time, and v_{sat} the saturation velocity. Assuming a constant λ_w, the integration under boundary condition $T_e(x=0)=T_0$,

$$T_e(x)=T_0+\frac{q}{2k}V(x)-\frac{q}{2k\lambda_w}\int_0^x V(\xi)e^{\frac{\xi-y}{\lambda_w}}d\xi$$

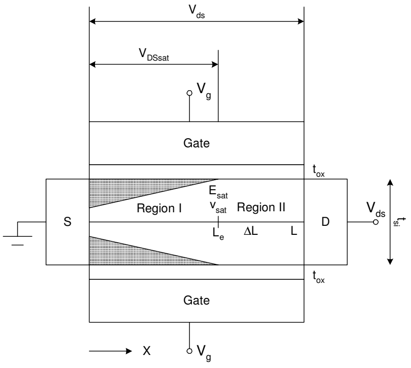
In linear region, the carrier velocity can be obtained from the mobility:

$$v(x)=\mu_n(x)E_x(x)=\frac{\mu_{n0}}{1+\alpha(T_e(x)-T_0)}E_x(x)$$

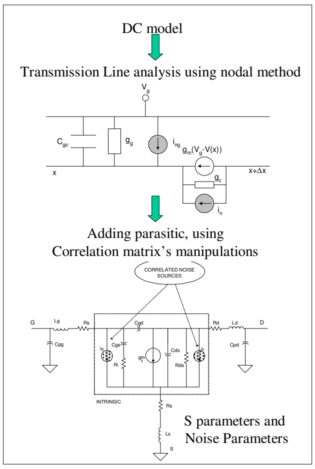
$$\alpha=\frac{2k\mu_{n0}}{q\lambda_w v_{sat}}$$

Finally the current is calculated using:

$$I_{DS}=\frac{W\int_0^{V_{Dsat}}\mu_{n0}Q(V)dV}{\int_0^{L_e}\left(1+\alpha(T_e(x)-T_0)\right)dx}$$



SMALL SIGNAL AND NOISE



DC model

Transmission Line analysis using nodal method

Adding parasitic, using Correlation matrix's manipulations

S parameters and Noise Parameters

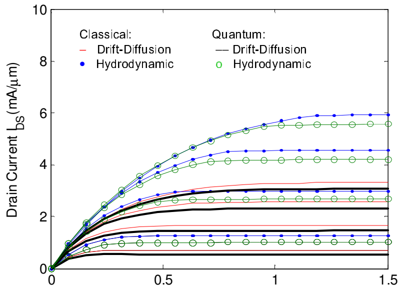
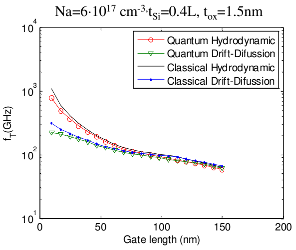
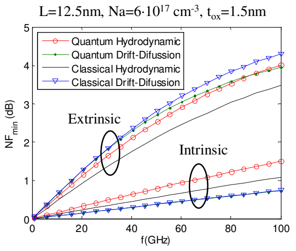


Fig 3. Drain current for DG MOSFET (Na=6·10^{17} cm^{-3}), L=50 nm, t_{si}=5 nm, t_{ox}=1.5 nm for classical charge control (V_{gs}-V_{TH}=0.5, 1, 1.5 and 2 V)





CONCLUSIONS

The results show important differences in drain current, f_T and noise performances between drift-diffusion and hydrodynamic models for short gate lengths. These differences are due to the velocity overshoot increasing the transconductance, and the hot-carrier effects in the noise temperature.

Acknowledgements

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