

Self-consistent simulation of bented channel DGMOSFETs

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Abstract—Nowdays semiconductor manufacturing technology approaches its limit of miniaturization. There is a need for devices with low impact of miniaturization on its functionality. We present here simulation results of double-gate MOSFET devices with variable silicon channel width. We simulated devices using drift-diffusion model to analyze the results of segmentation. We also present some results of curved channel transistor.

Index Terms—semiconductor device modeling, nonlinear equations, double-gate FETs, MOSFETs

I. INTRODUCTION

Miniaturization is the driving force of microelectronics. Today it reached the regime of decanometers and quantum mechanical effects begin to play an important role in functionality of devices changing device characteristics dramatically [1]. There are some devices that can be manufactured using the same technology but they are not effected by miniaturization caused effects [2]. One of them is double-gate metal-oxide field-effect transistors (DG-MOSFETs)[3]. Unlike conventional MOSFETs DGMOSFETs have two gates which controls the channel between them [4] shown on Fig. 1.

Because of some reasons the channel width can be modulated while the total thickness of the device remains constant. Modulation can be caused intentionally by design or randomly by manufacturing failure. Internal investigation can't be performed so we have to analyze characteristics measurable on contacts of the device. We showed earlier [4], [5] that channel segmentation causes measurable differences in characteristics. Here we examine effects of bented channel introducing special features in device characteristics.

II. MODEL DESCRIPTION

A. Physical model

Simulation of semiconductor devices means solution of an electromagnetic problem that describes driving force of charge carriers and solution of a transport model that describes transport of charge carriers through the force [6]. In cases when quantummechanical effects needed to be taken into account we have to solve Boltzmann Transport Equation. In our case of exotic devices that means not so simply geometries,

quantummechanical effects do not play a significant role, a simpler model can be used.

The model used is the drift-diffusion model. Under the assumption of Boltzmann statistics, the time-dependent drift-diffusion model consists on electromagnetics (1) and continuity equations of electrons (2) and holes (3) that count for transport of charges. Transport equations represent a highly nonlinear problem.

$$\varepsilon\Delta\varphi = q(n - p - C) \quad (1)$$

$$\frac{\partial n}{\partial t} = -\frac{1}{q}\nabla\left(q\mu_n n\nabla\left(\varphi - \frac{kT}{q}\log\left(\frac{n}{n_i}\right) + \gamma_n\right)\right) - r \quad (2)$$

$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla\left(q\mu_p p\nabla\left(\varphi + \frac{kT}{q}\log\left(\frac{p}{n_i}\right) - \gamma_p\right)\right) - r \quad (3)$$

where φ is the electrostatic potential, n and p are the electron and hole densities, ε is the electric permittivity, q is the electronic charge, k is the Boltzmann's constant, T is the absolute temperature, C is the ionized impurity density, n_i is the intrinsic density, and r is the recombination term. μ_n and μ_p are mobilities of electrons and holes, γ_n and γ_p are the quantum potentials of electrons and holes. In this case we do not need quantummechanical effects taken into account so $\gamma_n = 0$ and $\gamma_p = 0$.

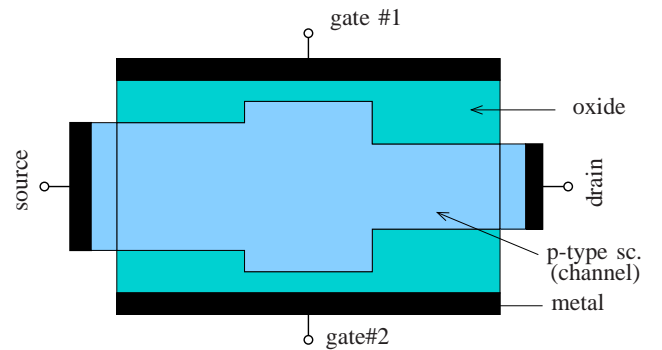


Figure 1: General idea of segmented double gate MOSFETs. A 3-segment segmented-DGMOSFET is shown with p-type channel doping.

The DD-model describes devices at a designer level as used since decades [7]. We will use results of DD simulations as an initial solution for more precious models [8] such as Monte-Carlo based particle method or Scattering Matrix Approach (SMA).

Approximating no change in time means a steady-state solution of problem. In case of steady-state problem transport equations (2) and (3) become a nonlinear Poisson-equations.

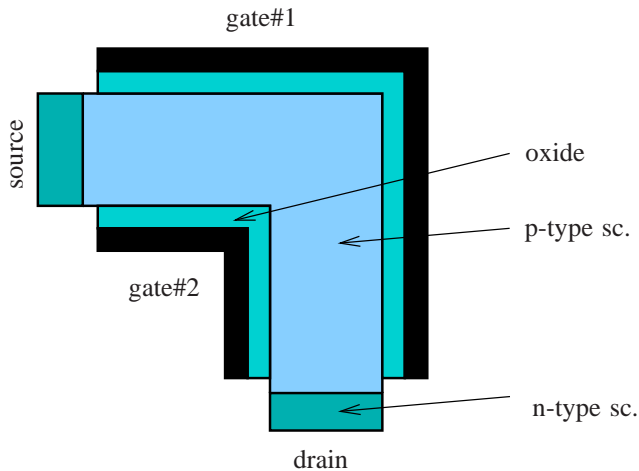


Figure 2: A special case of channel bending is a 90 degree curved DG MOSFET. Channel is made of p-type semiconductor, attached at the ends by n-type semiconductor. Gates are attached on an oxide layer onto the surface of channel.

B. Geometries

On the one hand we analyze different segmentations of channel to extend earlier investigations [5] using general geometry shown on Fig. 1. On the other hand we also analyze not conventional channel geometries such as in case of 90-degree curved DG MOSFET shown on Fig. 2.

Non conventional layouts can cause new characteristics and functionality of devices. That is a reason to select device shown on Fig. 2. In this case the inversion channel that is generated near oxide-semiconductor interface changes spatially can be investigated through bending.

C. Solution of model

We used commercial finite element based software COMSOL Multiphysics to solve the problems stated above. There were problems of solving nonlinear equations (2) and (3). There were need of carefully create a mesh on the geometry. We used a two-step solution method. First we solved an initial solution solving only (1) with constant carrier concentrations. After then using this initial solution we self-consistently solve the equations (1),(2) and (3).

III. RESULTS

Direct results of simulations are concentration distribution of electrons and holes inside devices. We calculate currents measurable on contacts using them. Characteristics are taken

using results of series of simulations. We use characteristics to extract small signal equivalent circuits of devices. On Fig. 3. shown a transconductance characteristics of segmented channel DG MOSFETs.

We show effects of geometrical parameters of bented channel MOSFETs on the device characteristics and small-signal equivalent circuits.

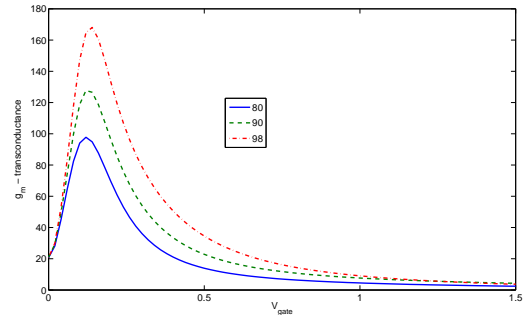


Figure 3: Transconductance as a function of gate voltage for different total gate-length in case of 50%-50% channel segmentation at channel lengths of 80, 90 and 98 nm.

IV. CONCLUSION

We step over the classical DG MOSFETs and show results of drift-diffusion model simulations of these layouts. Using these results a more accurate analysis of small-signal parameters can be performed.

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