TAUR'S MODEL: AN ANALYTICAL SOLUTION FOR DRAIN CURRENT IN UNDOPED BODY SDG MOSFET

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Abstract

This paper presents a long channel drain current model for undoped SDG MOSFET which is based on Taur's approach. The model is derived rigorously from the exact solution to Poisson's and current continuity equation without the charge-sheet approximation. The model involves implicit functions, iterations are required to solve the equations. It is shown that the results of the analytic model exhibit excellent agreement with two-dimensional (2-D) numerical simulation values, and yet, the expressions are continuous in all operation regions. Finally, the implementation in Matlab 7.5 is discussed to investigate the results.

Index Terms: *Symmetric Double-Gate, Drain–Current Model, Undoped Body.*

1. INTRODUCTION

AS CMOS scaling is approaching the limit imposed by gate oxide tunneling, double-gate MOSFET is becoming an intense subject of VLSI research because in theory it can be scaled to the shortest channel length possible for a given gate oxide thickness [1].For bulk MOSFETs, Pao-Sah's double integral based on gradual-channel approximation (GCA), although valid in all operation regions, cannot be carried out analytically due to the presence of both depletion and mobile charges in the integral [2]. This necessitates the charge-sheet approximation that would lead to further simplification to obtain a piecewise explicit current expression. However, charge-sheet-based models cannot properly describe volume inversion, a unique characteristic of double-gate(DG) MOSFETs in the subthreshold region [3]. Contrary to bulk MOSFETs, depletion charges in DG MOSFETs are negligible because the silicon film is undoped (or lightly doped). Thus, only the mobile charge term needs to be included in Poisson's equation. By extending this approach continuous analytic I-V model for DG MOS has been derived directly from Pao-Sah's integral without the charge sheet approximation this covers all regions of MOSFET Operation.

1.2DG-MOS Structure

The DG MOSFETs are the devices, which are having two gates on either side of the channel i.e. the channel is surrounded by the gate material on both the sides .One in upper side, known as top gate and another one is in the lower side of the channel, known as bottom gate . It gives better control of the channel by the gate electrodes .The channel is taken as undoped or lightly doped one[4].

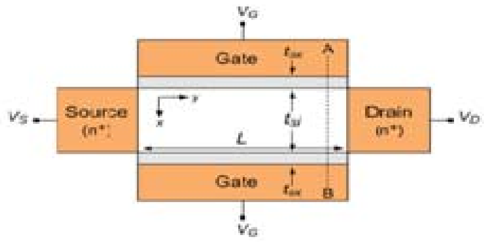

Fig -1: Schematic diagram of a DG MOSFET

Fig. 1 shows the schematic diagram of a symmetric double-gate MOSFET. Same voltage is applied to the two gates having the same work function. At zero gate voltage, the position of the silicon bands is largely determined by the gate work function. This is because as long as the thin silicon is lightly-doped and the depletion charge is negligible, the bands remain essentially flat throughout the thickness of the film [5].

2. TAUR'S MODEL FOR UNDOPED SDG-MOSFET

Consider an undoped (or lightly doped) SDG MOSFET shown schematically in Fig. 1. Poisson's equation along a vertical cut perpendicular to the Si film (Fig. 2) takes the following form with only the mobile charge (electrons) term [6]

$$\frac{d^2\Psi}{dx^2} = \frac{q}{\varepsilon_{si}} n_i e^{\frac{q(\Psi-V)}{kT}} \text{........}(1)$$

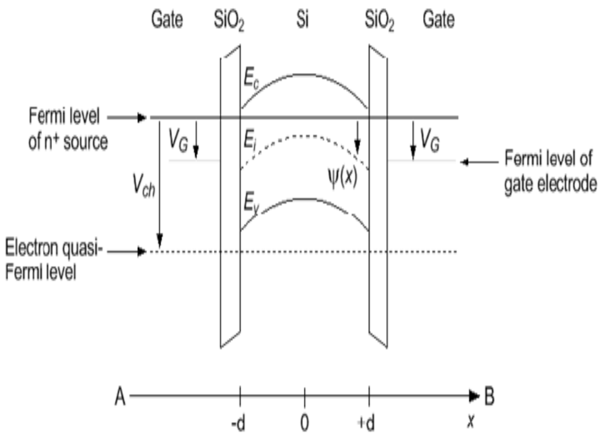

Fig -2: Schematic band diagrams of an symmetric DG nMOSFET along the vertical cut (AB).

Where q is the electronic charge, ε_{si} is the permittivity of silicon, n_i is the intrinsic carrier density, $\Psi(x)$ is the electrostatic potential and V is the electron quasi-Fermi potential. Here, we consider an nMOSFET with $\frac{q\Psi}{kT} >> 1$ so that the hole density is negligible. Since the current flows predominantly from the source to the drain along the y-direction, the gradient of the electron quasi-Fermi potential is also in the y-direction. This justifies the gradual channel approximation that V is constant in the x-direction. Equation (1) can then be integrated twice to yield the solution as

$$\psi(x) = V - \frac{2kT}{q} \ln\left[\frac{t_{si}}{2\beta}\sqrt{\frac{q^2 n_i}{2\varepsilon_{si}kT}}\cos\left(\frac{2\beta}{t_{si}}\right)\right] \text{........}(2)$$

Where β is a constant of y (independent of x) to be determined from the boundary condition

$$\varepsilon_{ox}\frac{V_g - \Delta\phi - \Psi(x = \frac{\pm tsi}{2})}{t_{ox}} = \pm\varepsilon_{si}\left.\frac{d\Psi}{dx}\right|_{x=\frac{\pm tsi}{2}} \text{........}(3)$$

Here ε_{ox} is the permittivity of oxide, Vg is the voltage applied to both gates, tsi and tox are the silicon and oxide thicknesses, and $\Delta\phi$ is the work function of both the top and bottom gate electrodes with respect to the intrinsic silicon. Substituting (2) into (3) leads to

$$\frac{q(V_g-\Delta\phi-V)}{2kT}-\ln\Big(\frac{2}{t_{si}}\sqrt{\frac{2\varepsilon_{si}kT}{q^2 n_i}}\Big)=\ln\beta-\ln(\cos\beta)+2r\beta\tan\beta........(4)$$

$$\text{where } \beta=\frac{t_{si}}{2}\sqrt{\frac{q^2 n_i}{2kT\varepsilon_{si}}}e^{q\psi_0/2kT} \text{ and } r=\frac{\varepsilon_{si}t_{ox}}{\varepsilon_{ox}t_{si}}........(5)$$

Now total mobile charge per unit gate area is can be given as

$$Q=2\varepsilon_{si}(d\psi/dx)_{x=t_{si}/2}=2\varepsilon_{si}(2kT/q)(2\beta/t_{si})\tan\beta........(6)$$

Using Pao-Sah's integral the expression for current can be given in terms of β as

$$I_{ds}=I_{ds0}[\beta\tan\beta-\frac{1}{2}\beta^2+r\beta^2\tan^2\beta]_{\beta_D}^{\beta_S}........(7)$$

$$\text{where } I_{ds0}=\mu\frac{W}{L}\frac{4\varepsilon_{si}}{t_{si}}\Big(\frac{2kT}{q}\Big)^2 \text{ and } 0<\beta<\pi/2$$

By defining

$$f_r(\beta)=\ln\beta-\ln(\cos\beta)+2r\beta\tan\beta........(8)$$

$$g_r(\beta)=\beta\tan\beta-\frac{1}{2}\beta^2+r\beta^2\tan^2\beta........(9)$$

Thus by using above results in eqn (7) we can calculate the drain current as done in following curves.

3. SIMULATIONS AND RESULTS

Based on the above results and Equations we can obtain the results for β and the drain currents as shown from fig 3--5.

1) Variation of $g_r(\beta)$ with $f_r(\beta)$ in linear scale.

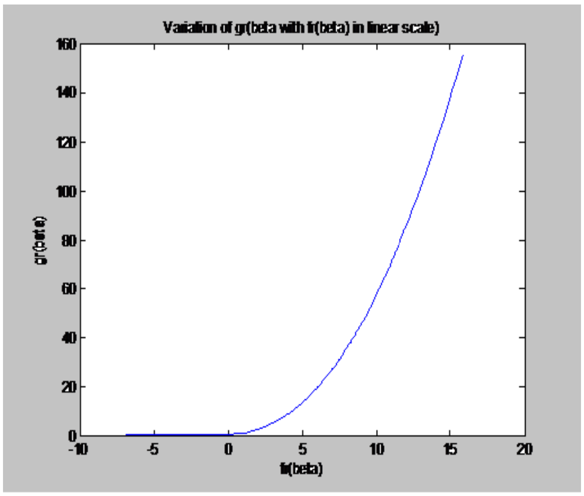

Fig -3: Plot of g_r versus f_r with β as a hidden parameter in linear scale.

2) Variation of $g_r(\beta)$ with $f_r(\beta)$ in logarithmic scale.

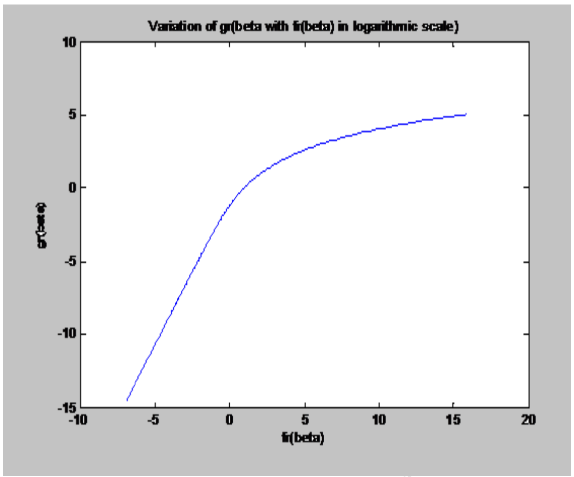

Fig -4: Plot of gr versus fr with β as a hidden parameter in logarithmic scale.

3) Variation of $g_r(\beta)$ with $f_r(\beta)$ in both linear and logarithmic scale

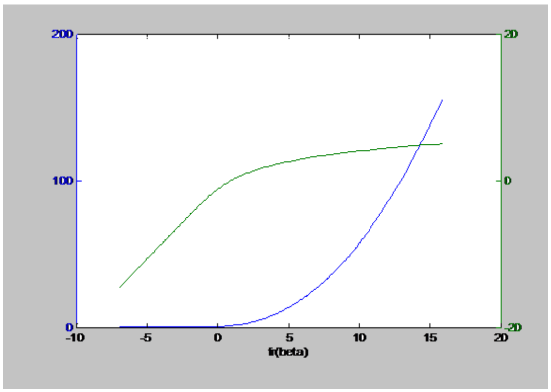

Fig -5: Plot of g_r versus f_r with β as a hidden parameter.Currents are plotted on both logarithmic (left) and linear(right) scales.

All the above simulation results are in excellent agreement with that of the Y.Taur's simulation results, which shows that we are correctly able to follow the Taur's approach.

CONCLUSION

In conclusion an analytic drain current model for modeling of long-channel SDG MOSFETs is presented which is implemented by using Matlab 7.5 and curves is plotted that shows the results of Taur's model is in complete agreement. Additional physical effects, e.g.,short-channel effect, quantum effect, and mobility model, need be incorporated into the long-channel core to build a complete DG-MOSFET compact model.

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