Physics-based compact model for the Surrounding-Gate MOSFET

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Abstract: We present a continuous analytic current-voltage model for cylindrical undoped (lightly doped) surrounding-gate (SGT) MOSFETs. It is based on the exact solution of the Poisson’s equation, and the current continuity equation without the charge-sheet approximation, allowing the inversion charge distribution in the silicon film to be adequately described. It is valid for all the operation regions (linear, saturation, subthreshold) and traces the transition between them without fitting-parameters, being ideal for the kernel of SGT-MOSFETs compact models. We have demonstrated that the current-voltage characteristics obtained by this model agree with three-dimensional numerical simulations for all ranges of gate and drain voltages.

Multiple-gate MOSFETs

Operation regions

1) Linear region above threshold, \( V_{th}^{(1)} \leq V_G - V_T \), as \( V_D \rightarrow V_T \).

2) Saturation region, \( V_{th}^{(1)} \leq V_G - V_T \) and \( 0 < V_D < V_T \), as \( V_D \rightarrow V_T \).

3) Subthreshold region, \( V_G < V_{th}^{(1)} \) and \( 0 < V_D < V_T \).

The saturation current depends on \( \psi_{LV}^{(1)} \) as expected for a MOSFET.

The subthreshold current is proportional to the cross-sectional area of the SGT-MOSFET and independent of \( \psi^{(1)} \).

Conclusions

We have presented a simple analytical 1.5 model suitable for compact modeling of undoped (lightly doped) SGT-MOSFETs. All the regions of operation and the transitions are correctly described by preserving the physics. In particular, the volume inversion, that cannot be captured by using the charge-sheet approximation, is well accounted for in this model.

The presented long-channel model is ideally suited for being the kernel of a SGT-MOSFET compact model. In order to complete the model, SCE, quantum effects, low and high field transport, noise, and more, should be added.

References

[3] D. Jiménez, J. J. Sáenz, B. Iñíguez, J. Suñé, L. F. Marsal, and J. Pallarès, “Modeling of 3-D numerical simulation from the source to the drain, the current can be written as:

\[ I_D = \frac{2}{3} q \mu_n C_{ox} W (V_G - V_T) \]

where \( W \) and \( L \) are the channel width and length, respectively.

Model validation

Transfer characteristics obtained from the analytic model compared with numerical simulations from DESSIS-IGS.

Output characteristics obtained from the analytic model compared with numerical simulations from DESSIS-IGS.

From (7), the drain current \( I_D^{(1)}(y, \phi, \rho) \) can be easily computed.