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Closed-form Current Equation for Short-Channel Triple-Gate FETs

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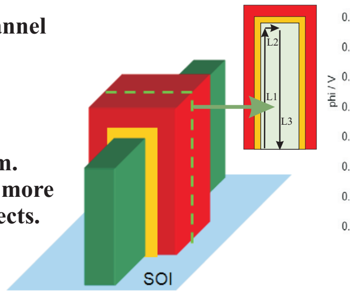
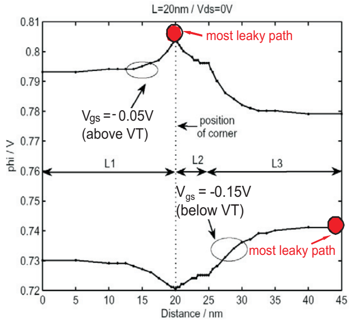
Analysis

In multi-gate FETs the position of the most leaky path within the channel cross section is bias dependent:

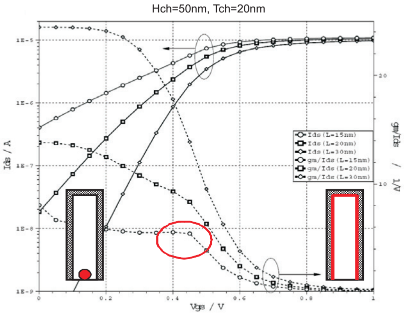
- **below V_T: at bottom center,**
- **above V_T: at silicon surface.**

If the channel is tall the top gate loses control on the channel bottom. Hence the subthreshold slope gets more degraded due to short-channel effects. This can result in a hump in the transconductance.





Potential in cross section at barrier (TCAD) and position of most leaky path.



Transfer characteristics and transconductance (TCAD). Movement of most leaky path (red) may result in a hump.

Modeling Approach

Our approach is based on a current equation from [1] which originally results from a 1D analysis of long-channel devices. We seperately calculate the mobile charge for below ($Q_{is,sth}$, $Q_{id,sth}$) and above ($Q_{is,str}$, $Q_{id,sth}$) threshold.

$$I_d = \mu W \left[\frac{2V_{th}}{L - x_{min}} (Q_{id,sth} - Q_{is,sth}) - \frac{\left(Q_{id,str}^2 - Q_{is,str}^2\right)}{4LC'_{ox}} \right]$$

Below threshold the channel length L is shortened by the distance x_{min} of the potential barrier from the source end of the channel.

The mobile charge below threshold in the bottom center of the channel is calculated from a 3D analytical model for the potential profile ϕ(x,y,z) at the barrier [2]:

$$Q_{is,sth} = \int\int q_i \; dy \; dz = \int\int \frac{n_i^2}{N_B} \; \exp\left(\frac{\phi(x_m, y, z)}{V_{th}}\right) \; dy \; dz$$

$$Q_{id,sth} = Q_{is,sth} \; \exp\left(-V_{ds}/V_{th}\right)$$

Channel charge above threshold results from a standard bulk MOS charge-sheet approximation:

$$Q_{is,str} = 2C'_{ox}(V_{gy} - V_{T,s})$$

$$Q_{id,str} = 2C'_{ox}(V_{gy} - V_{T,s} - V_{dss})$$

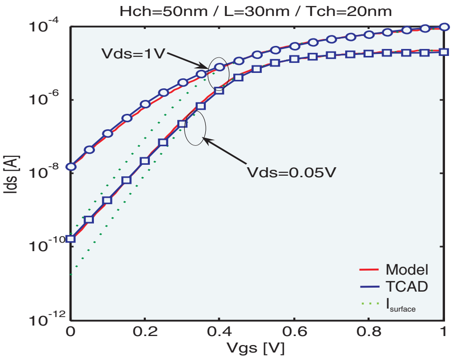
Voltage V_{gy} smoothly limits $V_{gs} > V_T$ obtaining the subthreshold slope of the surface channel current [3]. Slope and V_T at the silicon-to-oxide interface are calculated from the 3D analytical model [2].

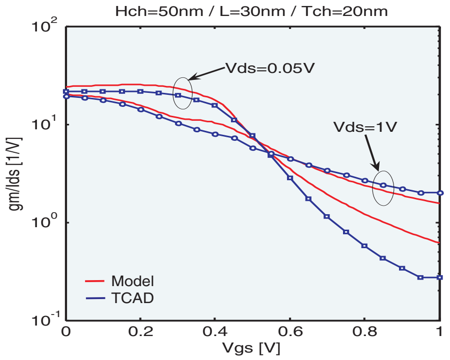
Results

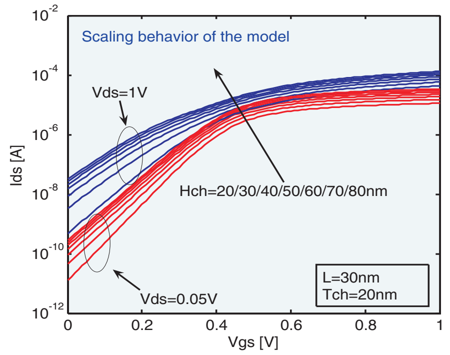
Plots show our model (red) compared to TCAD Sentaurus (blue). The hump in the transconductance is correctly predicted. The result of the surface current model only is show in green dotted lines. It is obvious that the surface current (green) dominates the total current (red) above V_T, whereas below threshold the slope degradation must result from the current in the channel center.

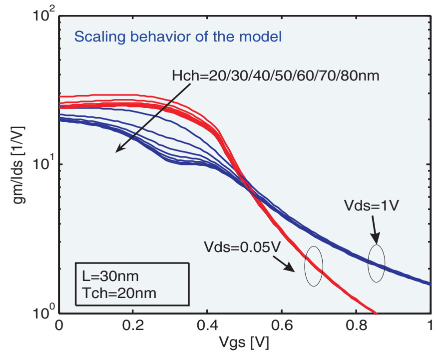
An increase of the channel height reduces the influence of the top gate. Therefore short channel effects as DIBL and slope degradation take place. The 3D closed-form analytical current equation allows a structure oriented analysis how the aspect ratio H_{ch}/T_{ch} of the channel has an impact on slope, V_T and the transcoductance.

The model does not introduce any fitting parameters for the 3D analysis. The only parameters are for mobility, saturation voltage and inversion potential at threshold.









References:

[1] J. He et al.: A non-charge-sheet analytic theory for undoped symmetric double-gate MOSFET from the exact solution of Poissons equation using SSP approach, Proceedings Workshop Compact Model., NSTI-Nanotech, Boston, MA, 2004.
[2] A. Kloes et al.: Three-dimensional closed-form model for potential barrier in undoped FinFETs resulting in analytical equations for VT and subthreshold slope, IEEE TED, Vol. 55, No. 12, 2008
[3] A. Kloes: Unified current equation for predictive modeling of submicron MOSFETs, Solid-State Electron., Vol. 49, 2005.

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