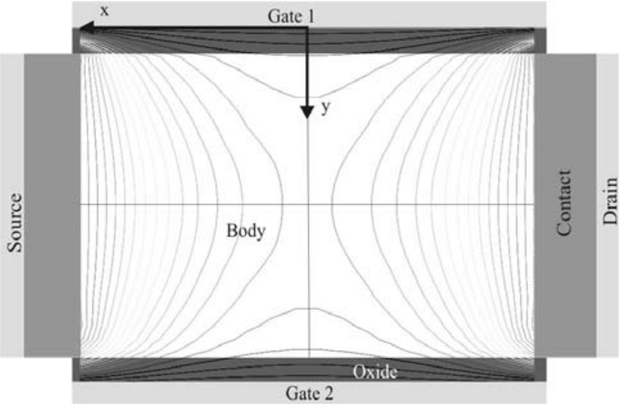
Verification of a Novel 2D Compact Model for Short-Channel Double Gate MOSFETs

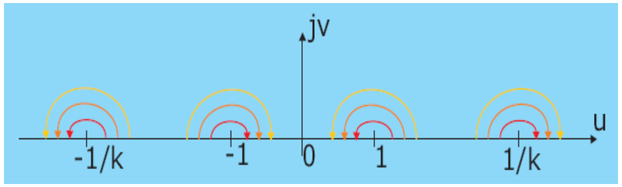
S. Kolberg, H. Børli, and T. A. Fjeldly
University Graduate Center (UNIK), Norwegian University of Science and Technology, Kjeller, Norway



Objective: Establish framework for precise, compact 2D modeling of short-channel, nanoscale DG MOSFETs. Consider *subthreshold*, *near threshold*, and *strong inversion*

Subthreshold: 2D capacitive coupling between the contacts dominates the electrostatics

- Map body into upper half plane of transformed (u,iv)-plane using ***conformal mapping*** (Schwartz-Christoffel transform)
- Solve ***Laplace's equation*** in (u,iv)-plane (low-doped body)
- Map back to (x,y)-plane



Schwartz-Christoffel transformation

$$z = x + iy = \frac{L}{2}\frac{F(k, u+iv)}{K(k)}$$

$$F(k,w) = \int_0^w \frac{dw'}{\sqrt{(1-w'^2)(1-k^2w'^2)}}, \quad K(k) = F(k,1)$$

$$\varphi(u,v) = \frac{1}{\pi}\left\{ \begin{aligned} &(V_{GS2} - V_{FB})\left[\pi - \tan^{-1}\left(\frac{1-ku}{kv}\right) - \tan^{-1}\left(\frac{1+ku}{kv}\right)\right] + (V_{GS1} - V_{FB})\left[\tan^{-1}\left(\frac{1-u}{v}\right) + \tan^{-1}\left(\frac{1+u}{v}\right)\right] \\ &+ V_{bi}\left[\tan^{-1}\left(\frac{1-ku}{kv}\right) - \tan^{-1}\left(\frac{1-u}{v}\right)\right] + (V_{bi} + V_{DS})\left[\tan^{-1}\left(\frac{1+ku}{kv}\right) - \tan^{-1}\left(\frac{1+u}{v}\right)\right] \end{aligned} \right\}$$

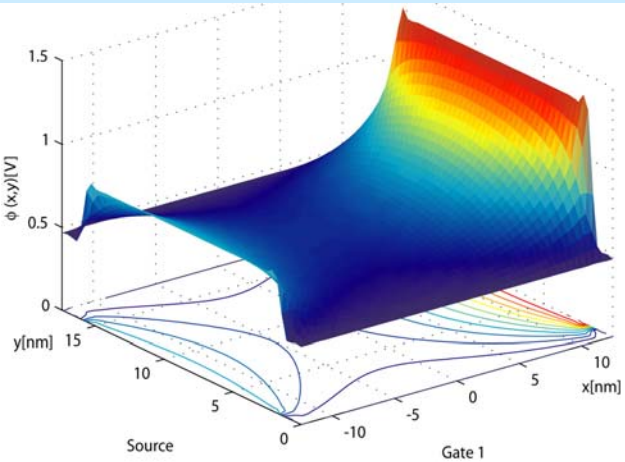
Supported by the EU NoE
SINANO (Silicon-based Nanodevices)

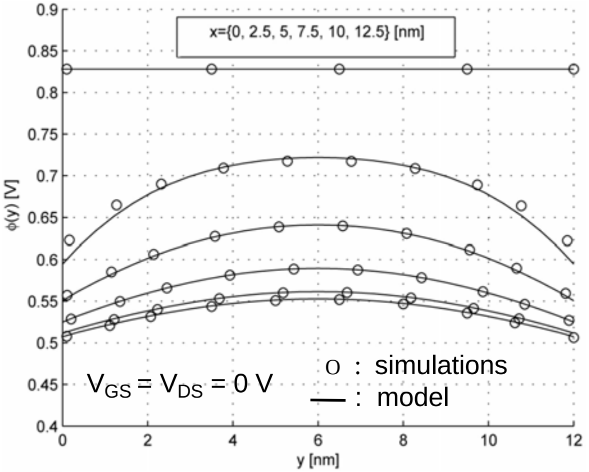
UniK/NTNU

Electrostatics

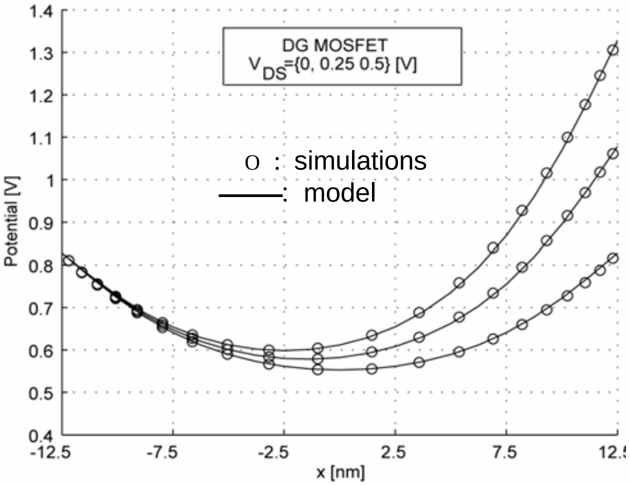
Device specifics: L = 25 nm, t_{si} = 12 nm, t_{ox} = 1.6 nm, ε_{ox} = 7, N_d = 10^{15} cm^{-3}, midgap gate

- *Subthreshold*





Subthreshold gate-to-gate pot. profiles



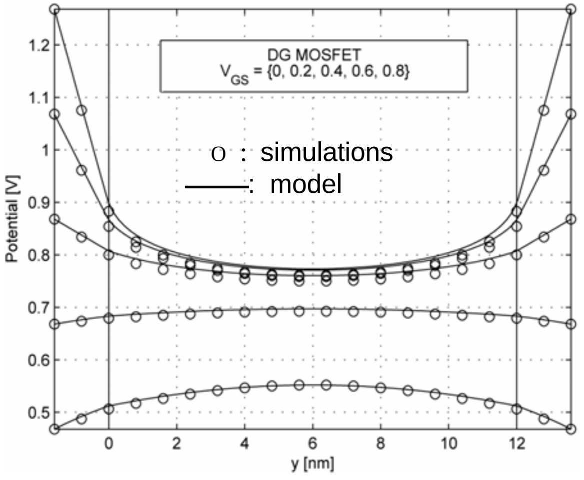
Subthreshold source-to-drain pot. profiles

- *Near threshold*

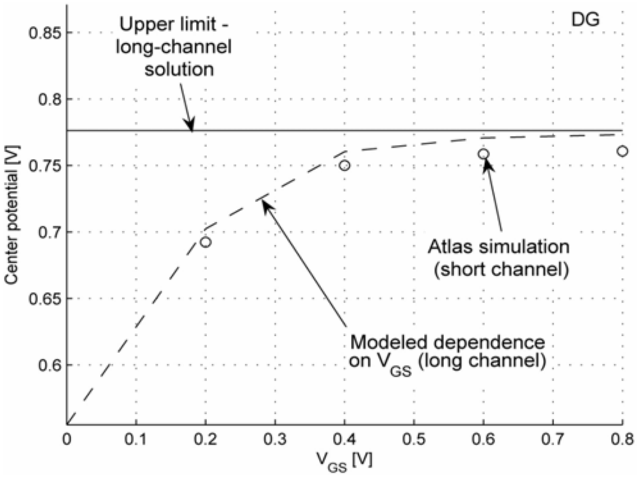
Effects of electrons comparable to that of capacitive coupling. Solve self-consistently.

- *Strong inversion*

Electrons dominate electrostatics. Use long-channel solution according to Taur (2001).



Central gate-to-gate pot. Profiles vs. V_{GS}



Center potential versus V_{GS}

Drift-diffusion drain current

Procedure

- Determine 2D barrier topography
- Calculate electron distribution
- Find short-channel effects including DIBL
- Calculate current – drift-diffusion or ballistic

Subthreshold and near threshold

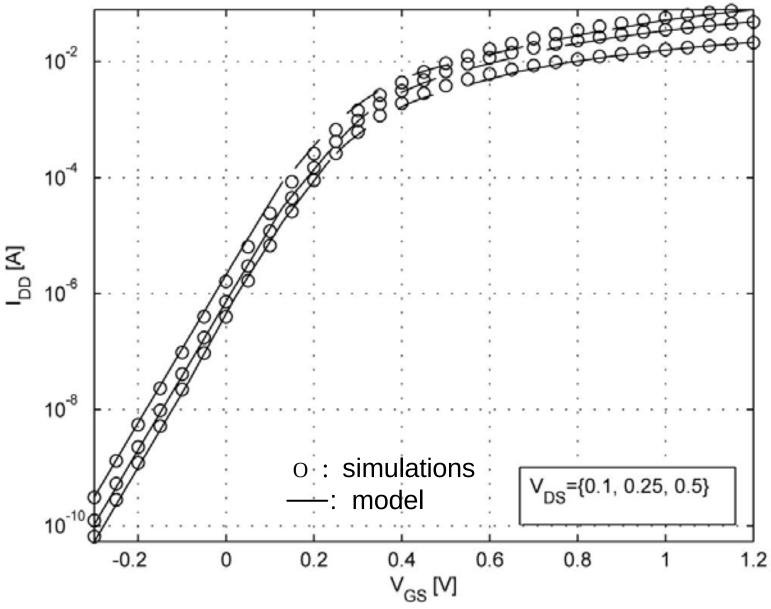
Use barrier shape derived self-consistently.
Assume that the current is ’small’:

$$I_{DD} = -q\mu_n n_s(x)\frac{dV_F(x)}{dx} = \frac{q\mu_n V_{th}\left(1-e^{-V_{DS}/V_{th}}\right)}{\int_0^L \frac{dx}{n_{so}(x)}}$$

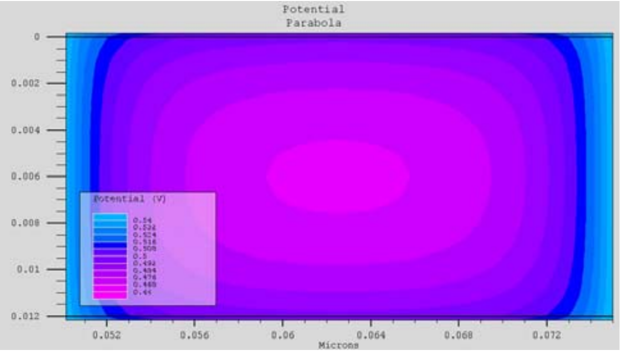
$n_{so}(x)$: surface concentration of electrons

Strong inversion

Use long-channel formalism by Taur et al. (2004)



Modeled and simulated DD drain current for DG MOSFET



Summary

- Compact 2D modeling framework established for short-channel, nanoscale DG MOSFETs by means of conformal mapping techniques

- Precise description of:
  - *2D device barrier topography*
  - *Short-channel effects including DIBL*
  - *Self-consistency at moderate and high electron densities*
  - *Drift-diffusion transport*

- Model verified by numerical simulations