Development and Verification of a Precise Compact Model for Short-Channel Gate-All-Around MOSFETs

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Objective: Develop framework for precise, compact modeling of short-channel, nanoscale GAA MOSFETs. Consider *subthreshold*, *near threshold*, and *strong inversion*

Adapt 2D solution of electrostatics for DG MOSFETs (based on conformal mapping techniques) to the gate-all-around (GAA) device.

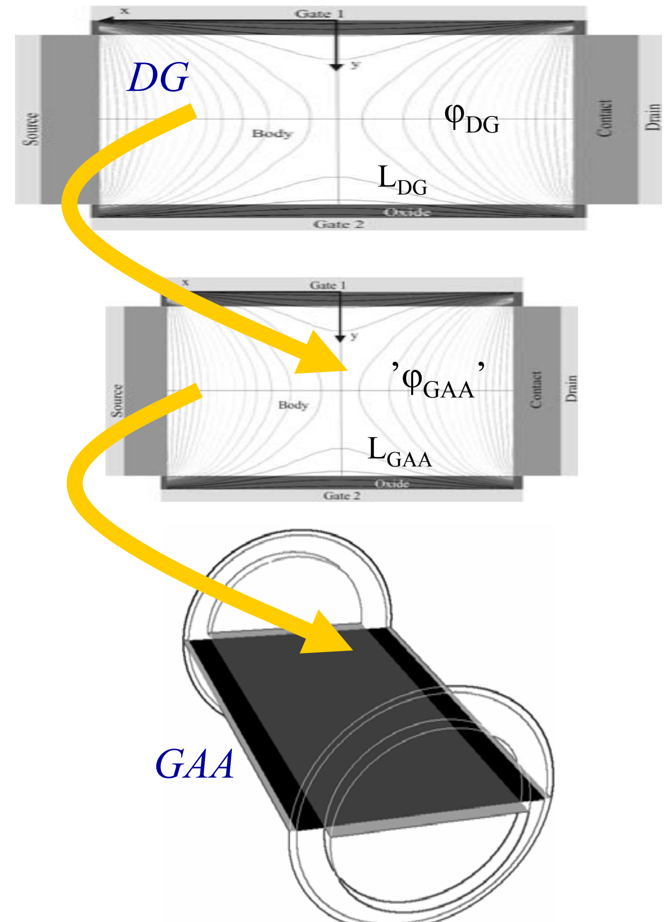
Subthreshold: Dominated by capacitive coupling.

- Find potential distribution $\varphi_{DG}(x,y)$ for DG MOSFET with length $L_{DG} = L_{GAA}\lambda_{DG}/\lambda_{GAA}$.

- Field penetration from source into body of GAA and DG MOSFETs:

$$\lambda_{GAA} = r_{si}\sqrt{\frac{1}{4} + \frac{\varepsilon_{si}}{2\varepsilon_{ox}}\ln\left(1 + \frac{t_{ox}}{r_{si}}\right)} \qquad \lambda_{DG} = \sqrt{\frac{\varepsilon_{si}}{2\varepsilon_{ox}}\left(1 + \frac{\varepsilon_{ox} t_{si}}{4\varepsilon_{si} t_{ox}}\right) t_{si} t_{ox}}$$

- Compress $\varphi_{DG}(x,y)$ in x-direction to length L_{GAA}, $\rightarrow$ '$\varphi_{GAA}(x,y)$'. This satisfies boundary conditions, matches field penetration, and closely reproduces structural features of exact φ_{GAA}.



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GAA MOSFET - Electrostatics

Near threshold:

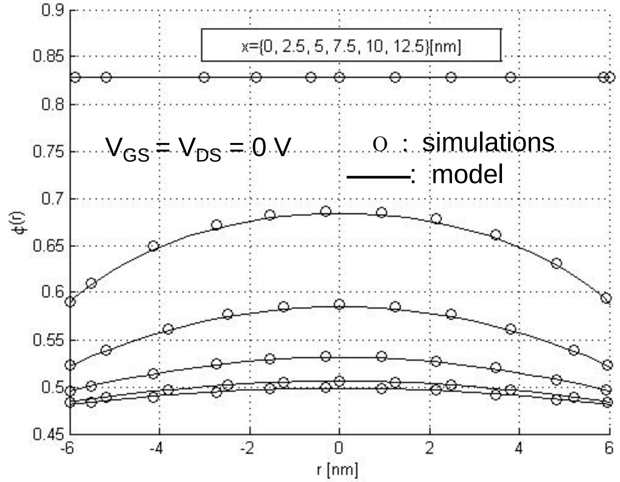
Effects of electrons comparable to that of capacitive coupling. Solve self-consistently for cylinder geometry

Strong inversion:

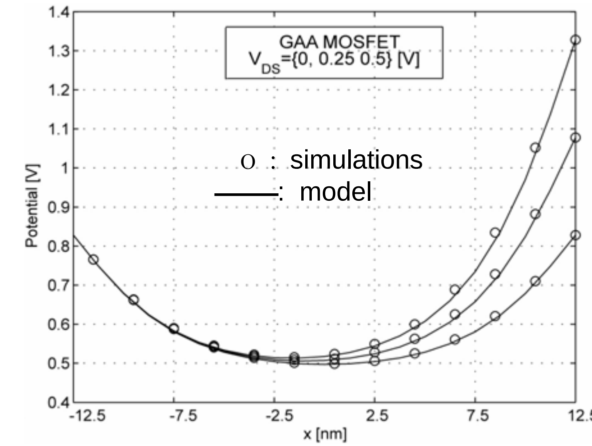
Electrons dominate electrostatics. Use long-channel solution for cylinder geometry according to Iniguez et al. (2005).

GAA MOSFET specifics

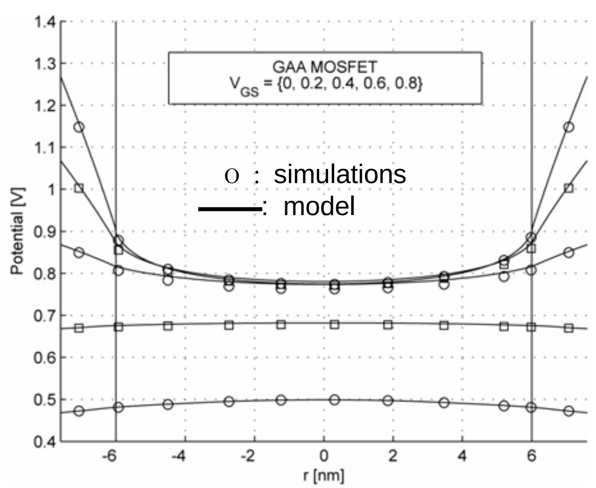
$L = 25$ nm, $t_{ox} = 1.6$ nm,
$\varepsilon_{ox} = 7$, $r_{Si} = 6$ nm
$\lambda_{DG}/\lambda_{GAA} = 1.45$,
midgap gate material



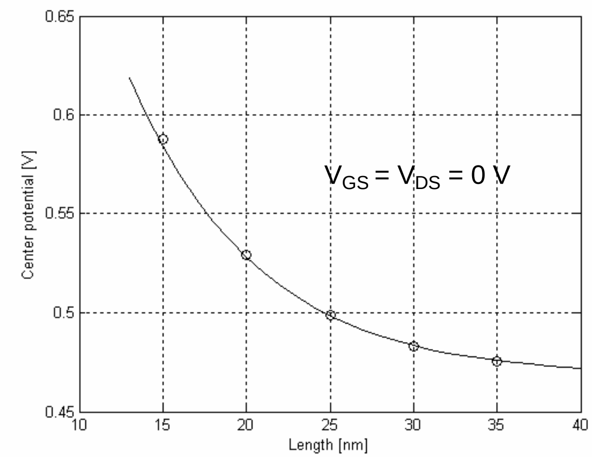
Subthresgold G-G potential profiles at different positions along the S-D-axis



Subthreshold potential profiles along the S-D-axis for different V_{DS}



Central gate-to-gate potential profiles for different V_{GS}



Scaling of center potential with gate length in subthreshold

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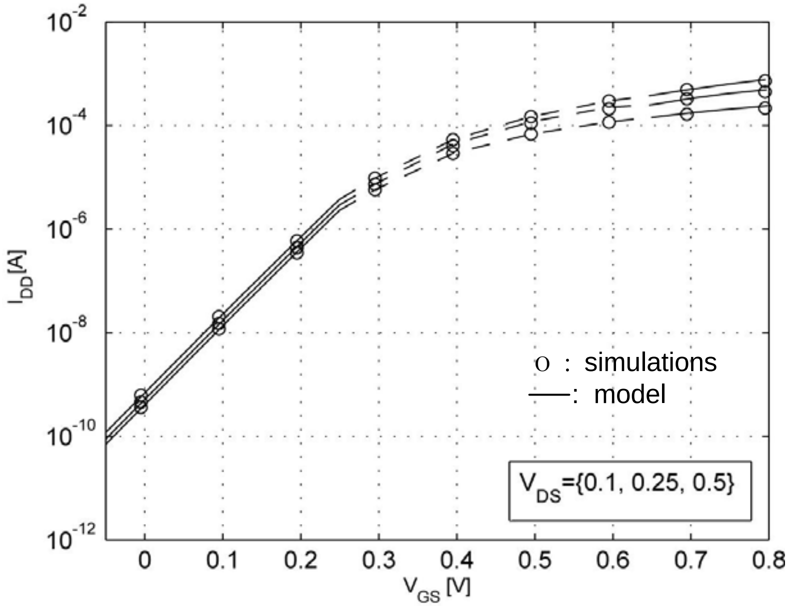
GAA MOSFET
Drift-diffusion drain current



Modeled and simulated DD drain current for GAA MOSFET

Procedure

- Determine barrier topography in cylindrical geometry
- 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 drain 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 discussed by Taur (2004) (DG) and Iniguez (2005) GAA.

Summary

- Compact modeling framework established for short-channel, nanoscale GAA MOSFETs by adapting 2D model for DG MOSFET (based on 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

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