Quantum compact model for ultra-short and ultra-narrow body FinFETs

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Outline

1 Research team

2 QME simulation

3 QME modeling

4 Model validation

5 Conclusions

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Research team and collaboration

Compact modeling of advanced devices

- Professor - Christophe LALLEMENT
- Associate professor - Fabien PREGALDINY
- Assistant professor - Morgan MADEC
- PhD student – Mingchun TANG
- PhD student – Nicolas CHEVILLON

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Collaboration
Dr. Jean-Michel SALLESE
LEG, EPFL

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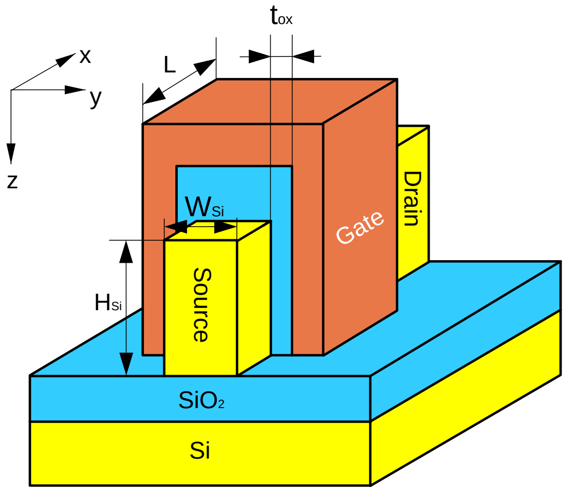
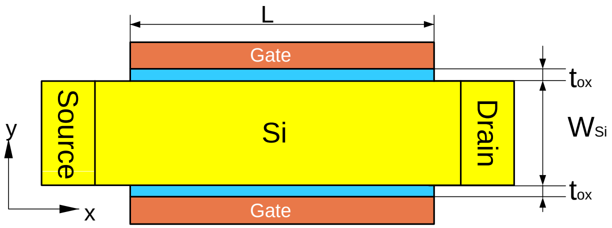
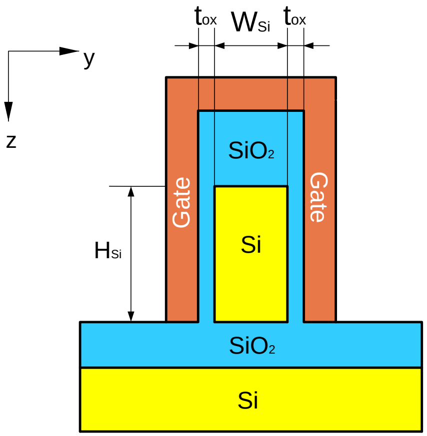
Definition



(a)

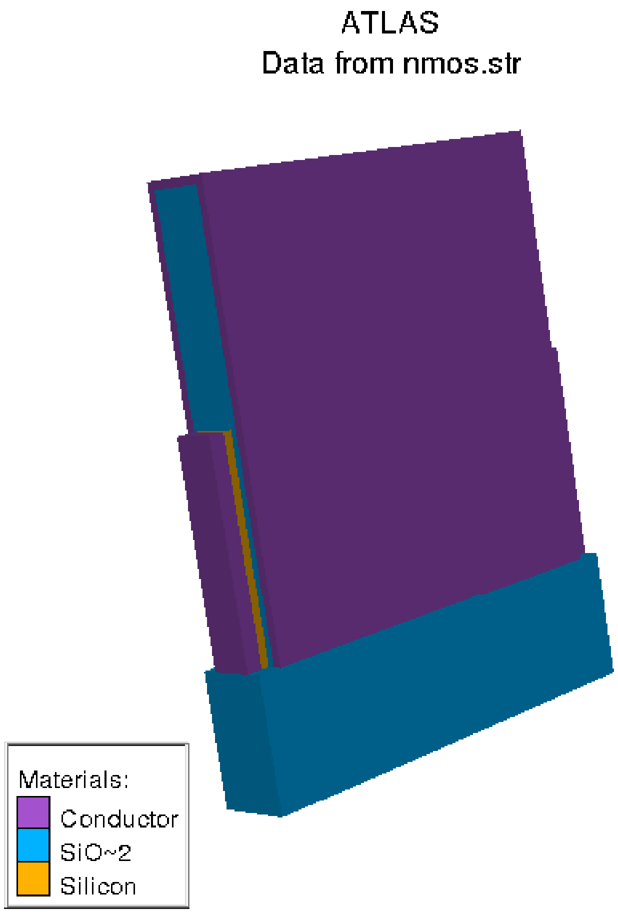


(b)

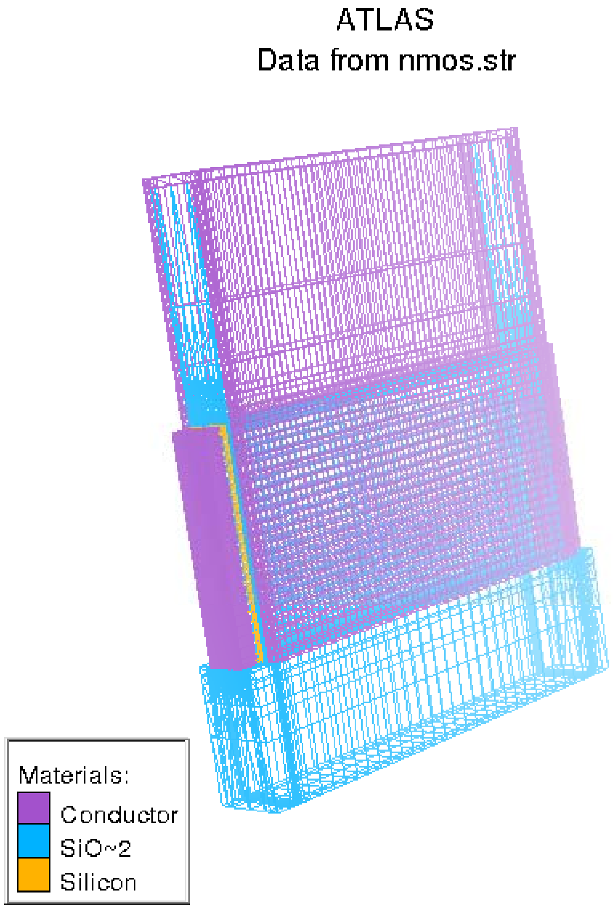


(c)

3D Simulation mesh



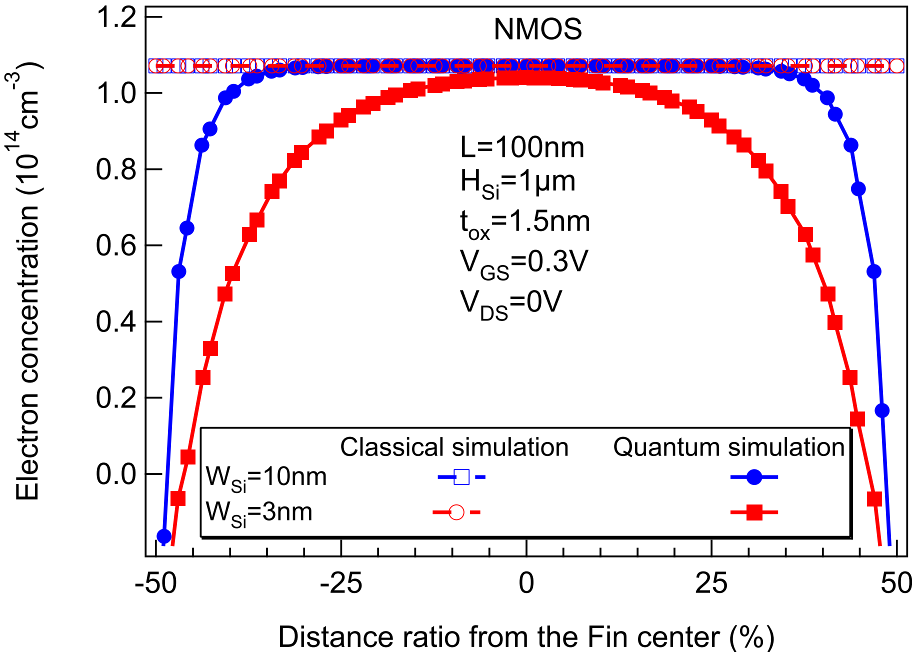
3D structure

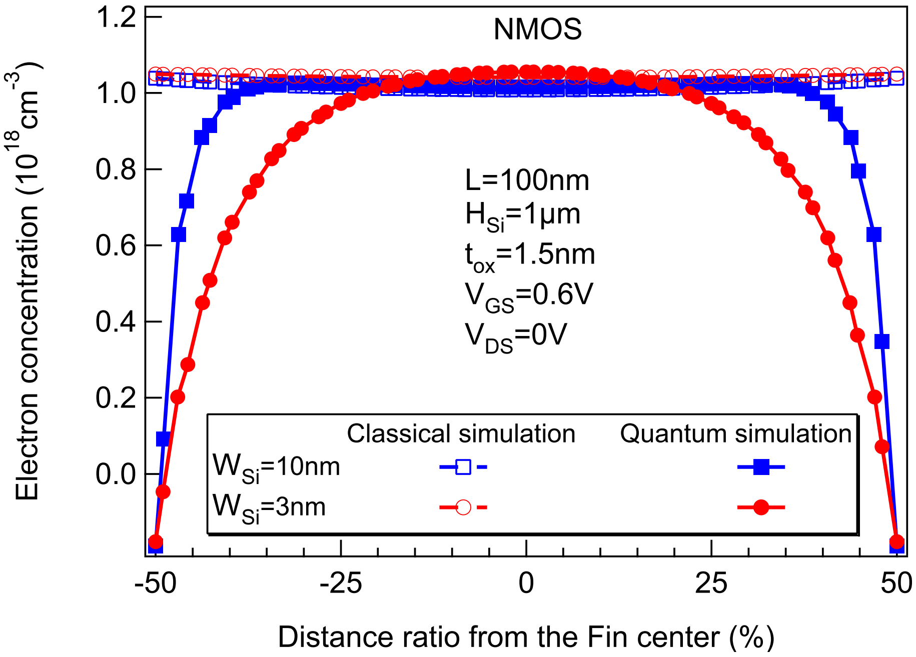


3D mesh

L=100nm, H_{Si}=50nm, W_{Si}=10nm

Electron concentration distribution in silicon width direction





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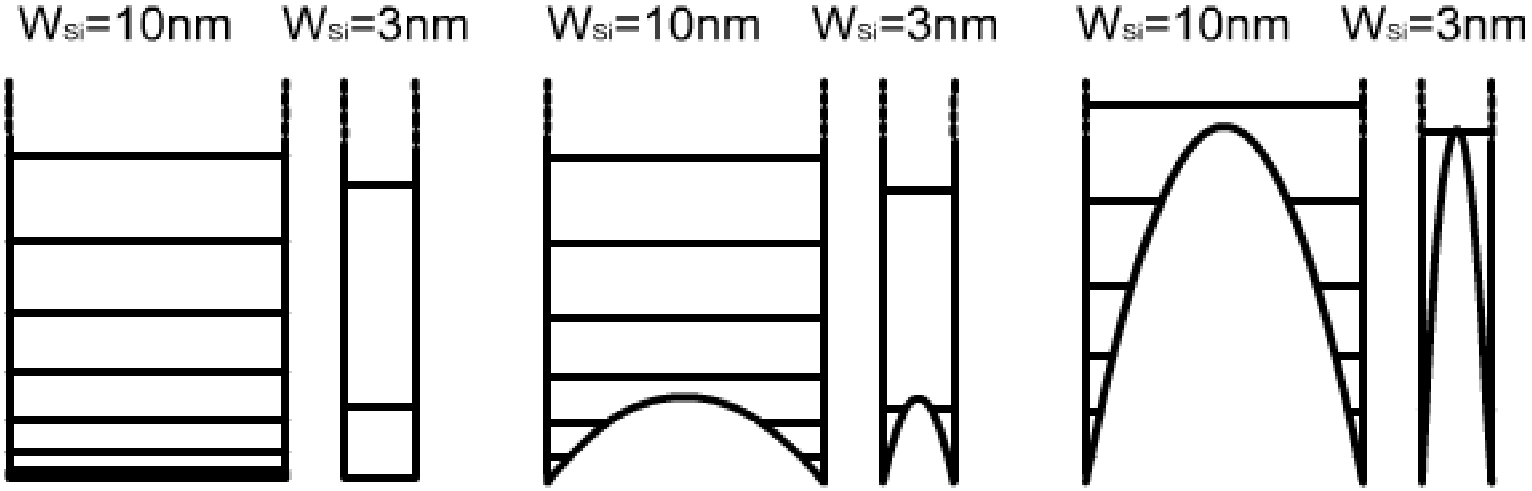
Normalization of the electric quantities

Electric quantities	Normalization factors
Voltages	$U_T = k \cdot T / e$
Currents	$I_s = 4 \cdot \mu \cdot C_{ox} \cdot U_T^2 \cdot H_{Si} / L$
Charges	$Q_0 = 4 \cdot C_{ox} \cdot U_T$
Capacitances	$C_{ox\_total} = 2 \cdot C_{ox}$

[1] J.-M. Sallese, F. Krummenacher, F. Prégaldiny, C. Lallement, A. Roy and C. Enz, “A design oriented charge-based current model for symmetric DG MOSFET and its correlation with the EKV formalism,” *Solid-State Electronics*, vol. 49, pp. 485-489, 2005.

Energy quantization due to QME



Flat band (a)

Weak inversion (b)

Strong inversion (c)

QME correction

$$E_{mn} \cong \frac{\hbar^2 \cdot \pi^2}{2 \cdot U_T} \cdot \left[\left(\frac{m}{m_z \cdot W_{Si}} \right)^2 + \left(\frac{n}{m_y \cdot H_{Si}} \right)^2 \right]$$

QME correction

$$E_m \cong \frac{\hbar^2 \cdot \pi^2}{2 \cdot U_T} \cdot \left(\frac{m}{m_z \cdot W_{Si}} \right)^2$$

QME correction

$$E_1 \cong \frac{\hbar^2}{2 \cdot m_{eff} \cdot U_T} \cdot \left(\frac{\pi}{W_{Si}} \right)^2$$

QME correction

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$$\boxed{\Delta E_{qm} = E_1 \cdot \left(1 + g(W_{Si}, v_g)\right)}$$

with $g(W_{Si}, v_g) = \alpha_{qm1} + \alpha_{qm2} \cdot \frac{(v_g - v_{to}) + \sqrt{(v_g - v_{to})^2}}{2} + \alpha_{qm3} \cdot \frac{(v_g - v_{to})^2 + (v_g - v_{to}) \cdot \sqrt{(v_g - v_{to})^2}}{2}$

and
$$\begin{cases} \alpha_{qm1} = a_1 + a_2 \cdot W_{Si} \\ \alpha_{qm2} = b_1 + b_2 \cdot W_{Si} + b_3 \cdot W_{Si}^2 \\ \alpha_{qm3} = c_1 + c_2 \cdot W_{Si} + c_3 \cdot W_{Si}^2 \end{cases}$$

PARAMETER	VALUE
a_1	-0.83
a_2	0.033
b_1	-0.011
b_2	0.0029
b_3	0.000215
c_1	0.00035
c_2	-0.00017
c_3	0.000046

QME correction

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$$\boxed{v_{to\_qm} = v_{to} + \frac{\Delta E_{qm}}{e}}$$

[2] M. Tang, F. Prégaldiny, C. Lallement and J.-M. Sallese, “Quantum compact model for ultra-narrow body FinFET,” *in Proc. ULIS’09*, Aachen, Germany, March 18-20, 2009.

Complete compact model (Drain current)

Normalized drain current:

$$i = -q_{m0}^{2}\left(v_g, v_{ch}\right) + 2\cdot q_m(v_g + \Delta v_{th}, v_{ch}) + \frac{2}{\alpha}\cdot \ln\left(1 - \alpha \cdot \frac{q_m(v_g + \Delta v_{th}, v_{ch})}{2}\right)\Bigg|_{q_{mS}}^{q_{mD}}$$

with

$$\begin{cases} \alpha = C_{ox}/C_{Si} \\ q_{m0} = f\left(v_g - v_{to\_qm} - v_{ch}\right) \\ q_m = f\left(\left(v_g - v_{to\_qm}\right)/n - v_{ch}\right) \\ \Delta v_{th} = \Delta v_{th_{DIBL}} + \Delta v_{th_{SCE}} = f\left(\gamma_{DIBL}, \gamma_{SCE}\right) \end{cases}$$

Normalized drain saturation voltage:

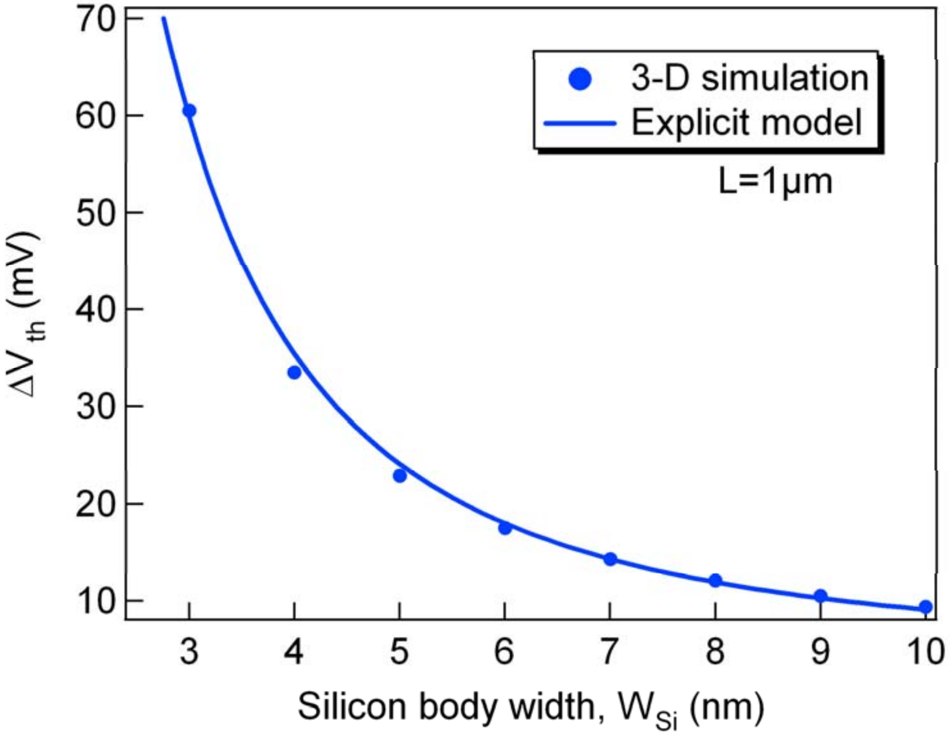
$$v_{dsat} = v_g - 2\cdot\phi_f + 2\cdot\frac{\varepsilon_{ox}}{\varepsilon_{Si}}\cdot q_{msat}$$

Channel length modulation:

$$\Delta L = f\left(v_g, v_d, v_{dsat}\right)$$

[3] M. Tang, F. Prégaldiny, C. Lallement and J.-M. Sallese, “Explicit compact model for ultra-narrow body FinFETs,” *Accepted in IEEE Transaction on Electron Devices* (March 2009).

Comparison with TCAD simulations



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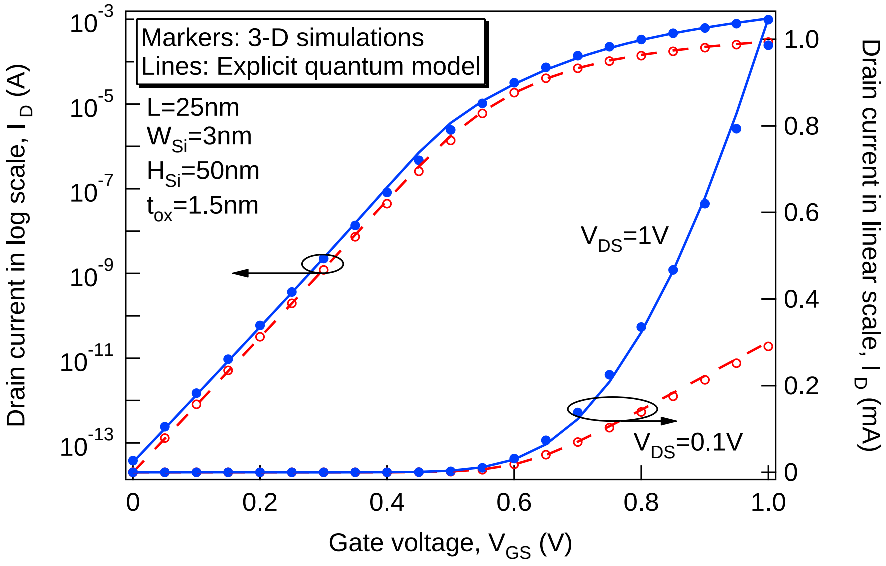
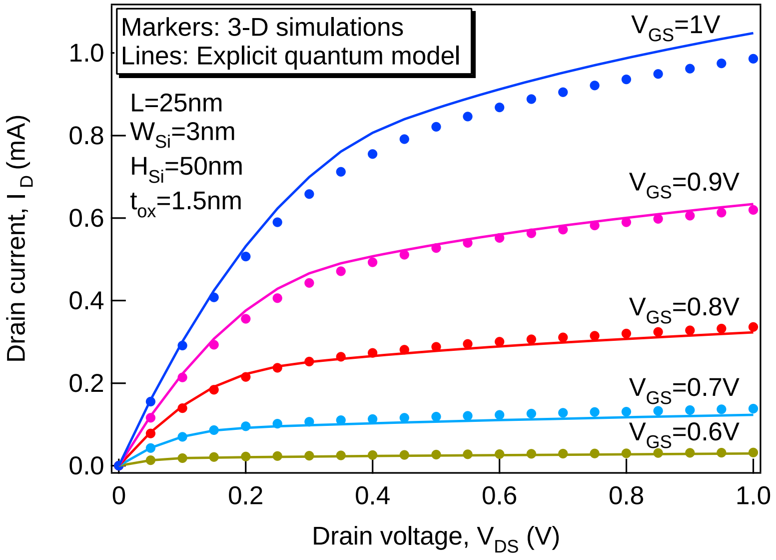
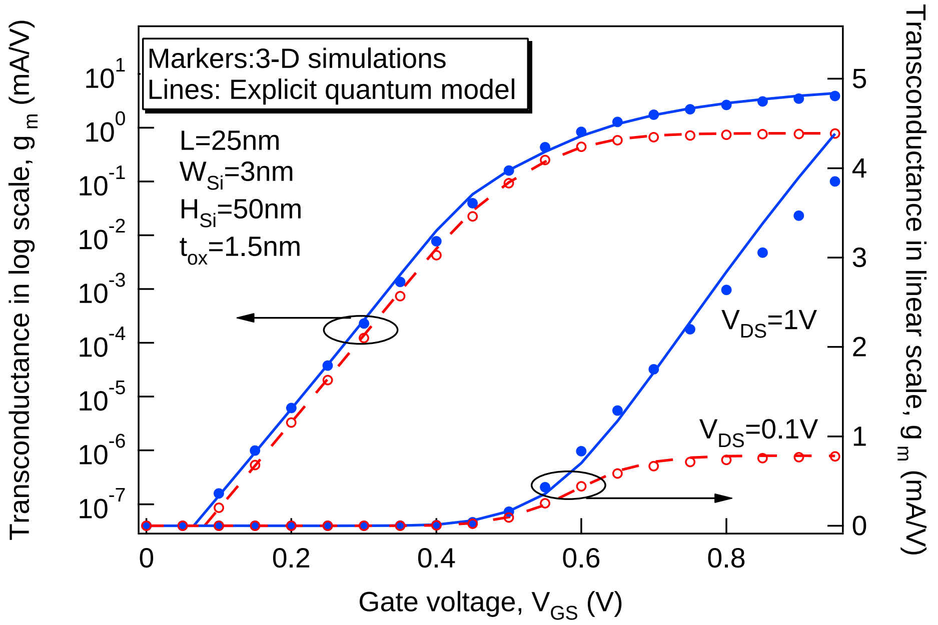
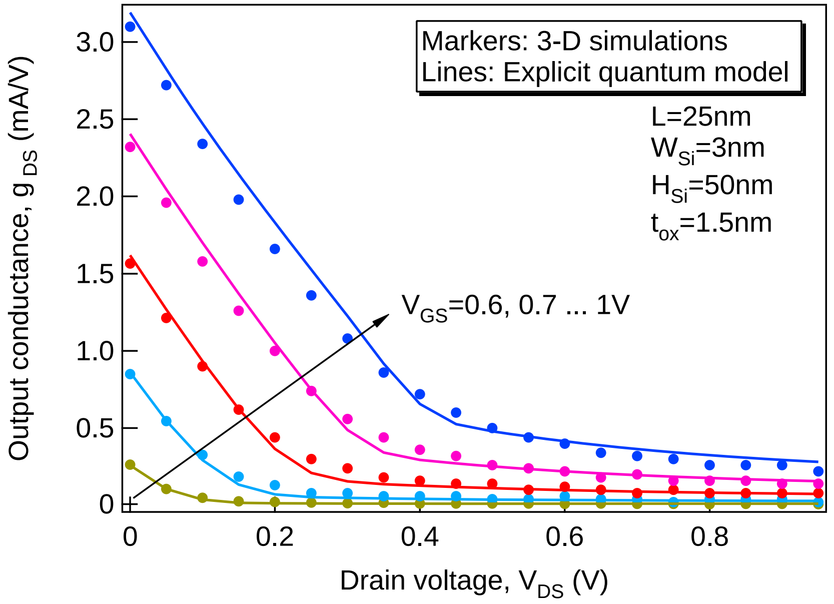




Model validation





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Included effects

- ✓ Quantum mechanical effects (QME)
  +
- ✓ SS degradation
- ✓ SCE & DIBL
- ✓ Drain saturation voltage
- ✓ Channel length modulation (CLM)

Valid range

- ➢ $I_D(V_{GS})$ & $I_D(V_{DS})$
- ➢ $g_m(V_{GS})$ & $g_{ds}(V_{DS})$
- ➢ L≥25nm
- ➢ W_{Si} ≥3nm
- ➢ H_{Si}≥50nm
- ➢ t_{ox}=1.5nm
- ➢ NMOS & PMOS

Perspectives

- ☐ Capacitance (work in process)
- ☐ Mobility degradation (work in process)
- ☐ Corner effect
- ☐ Thermal effect
- ☐ Ballistic transport
- ☐ Parameters extraction and optimization (work in process by N. Chevillon)
- ☐ Etc.

Thank You !