Semi-Analytical Model for Leakage Current in Ultra-Short DG MOSFET Based on NEGF Formalism

Fabian Hosenfeld$^{1,2}$ Michael Graef$^{1,2}$, Fabian Horst$^{1,2}$, Benjamin Iniguez$^2$, Francois Lime$^2$, Alexander Kloes$^1$

$^1$Competence Centre for Nanotechnology and Photonics, Technische Hochschule Mittelhessen, Gießen, Germany
$^2$Universitat Rovira i Virgili, Tarragona, Spain

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Introduction

Device Simulation
- Atomic scale
- Numerical solution

Poisson Solver
Transport Solver - NEGF

Multiscale Simulation
- Semi-analytical
- Closed form solution of Poisson -> NEGF

Poisson Solution
Transport Equation - 1D NEGF
Current

Circuit Simulation
- Terminal voltages/currents
- Analytical solution

Poisson Solution
Classical Transport Equations
Current
Advantages

**Advantage**
- Quantum effects in transport direction included
- Source to Drain tunneling
- Faster than classical device simulation

**Disadvantage**
- Not self consistent (to be shown if sufficient)
- Slower than compact model
Concept of the Modeling Approach

Electrostatics: 2D closed-form potential solution

One-dimensional NEGF

Device current


Electrostatics

- 2D closed-form solution of Poisson’s equation
- Based on conformal mapping
- Mobile charge neglected (subthreshold)
- Effective built-in potential model

One-dimensional conduction bands (slices from source to drain)
NEGF – Without Scattering

Hamiltonian:

\[ T = \frac{\hbar^2}{2ma^2} \]

Green’s function:

\[ G(E) = \left[ EI - H_L - \Sigma_1 - \Sigma_2 \right]^{-1} \]

Electron density:

\[ \tilde{\rho}(E) = \frac{F_1[A_1(E)] + F_2[A_2(E)]}{2\pi} \]

Integration over energy:

\[ \rho = \int \tilde{\rho}(E) dE \]

1D Current in one slice:

\[ I = -q \cdot Trace(\rho J_{op}) \]
Device Current

- Surface current
- Center current
- Parabolic function (Gate to Gate)
Results

- **Compared against TCAD 2D NanoMOS**

- **Device parameters:**
  - $t_{ch} = 2$ nm
  - $l_{ch} = 6$-10 nm
  - $l_{sd} = 10$ nm
  - $t_{ox} = 2.4$ nm
  - $N_{sd} = 2 \times 10^{20}$ cm$^3$
  - $\varepsilon_{ox} = 16 \times \varepsilon_0$
  - $m = 0.19 \times m_0$
  - $V_{ds} = 0.4$ V
  - $\theta=300$ K

- **Fitting of $V_{fb}$ (quantum confinement)**

- **Fitting of effective mass**
  $m = 0.29 \times m_0$ for $t_{ch} = 1$nm
Electron Density

$t_{ch} = 2 \text{ nm}, \ l_{ch} = 6 \text{ nm}, \ V_{ds} = 0.4 \text{ V}$
Model vs. TCAD: Drain Current

\[ I_d / \mu A/\mu m = 10^{2} \]

\[ V_{ds} = 0.4 \text{ V} \]

\[ L_{ch} = 10, 9, 8, 7, 6 \text{ nm} \]

\[ t_{ch} = 1 \text{ nm}, \quad L_{ch} = 6 \text{ nm} - 10 \text{ nm}, \quad V_{ds} = 0.4 \text{ V} \]
Model vs. TCAD: Drain Current

$V_{ds} = 0.4 \, \text{V}$
$
\vartheta = 75 \, \text{K}, 300 \, \text{K}$

$t_{ch} = 2 \, \text{nm}, l_{ch} = 6 \, \text{nm, 10 nm}$

$60 \, \text{mV/dec}$
$15 \, \text{mV/dec}$
Model vs. TCAD: Subthreshold Slope

\[ t_{ch} = 2 \text{ nm}, \; l_{ch} = 6 \text{ nm}, \; 10 \text{ nm}, \; V_{ds} = 0.4 \text{ V}, \; \theta = 75 \text{ K} - 300 \text{ K} \]
Future Work

- Speedup approach by avoiding numerical integration over energy:
  - Calculate current only at significant points in energy spectrum
  - Define empirical analytical function which allows for integration over energy in closed form

\[ t_{ch} = 2 \text{ nm}, \ V_{ds} = 0.4 \text{ V} \]
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