WCM2005: Forum

Surface Potential vs. Inversion Charge based approaches to MOSFET compact modeling

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Physics vs. Math

- Monte Carlo, Green's function, etc.
  e.g., Boltzmann transport eq.
- Partial differential eq.
  e.g., 2-D SCE simulation
- Ordinary differential eq.
  e.g., Schrodinger eq.
- Integrals
  e.g., Pao-Sah's integral
- Algebraic eq.
  - Implicit: e.g., charge sheet model, analytic potential model (DG)
  - Explicit: e.g., inversion-charge based approach

More physics

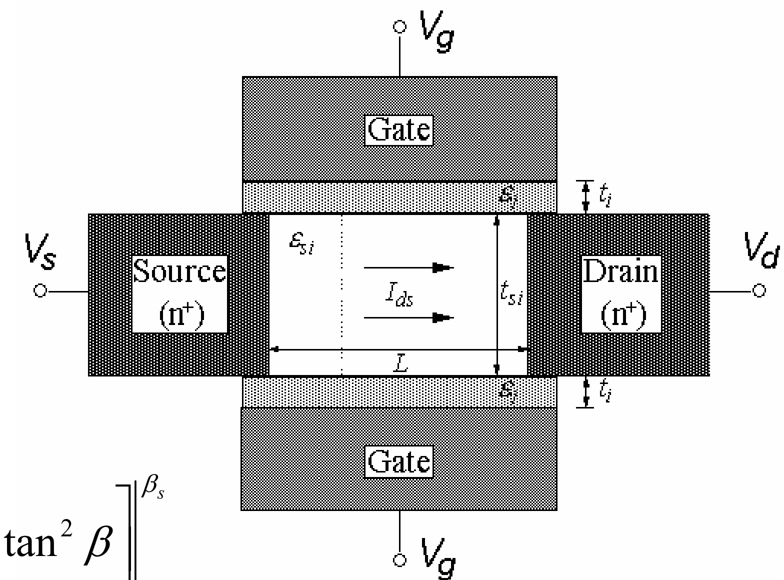
↓

Less physics

Source-Drain Symmetry: Source- or Body-Reference don't matter, Physics does!

Example: In Double-Gate MOSFET, there is no body to reference to!

Yet, source-drain symmetry is preserved in our analytic potential model, because no physics is lost in Poisson's and current continuity eqs.



$$I_{ds} = \mu \frac{W}{L} \frac{4\varepsilon_{si}}{t_{si}} \left(\frac{2kT}{q} \right)^2 \left[\beta \tan \beta - \frac{\beta^2}{2} + \frac{\varepsilon_{si} t_{ox}}{\varepsilon_{ox} t_{si}} \beta^2 \tan^2 \beta \right] \Bigg|_{\beta_d}^{\beta_s}$$

where $$\frac{q(V_g - \Delta\phi - V_s)}{2kT} - \ln\left[\frac{2}{t_{si}} \sqrt{\frac{2\varepsilon_{si} kT}{q^2 n_i}} \right] = \ln \beta_s - \ln[\cos \beta_s] + \frac{2\varepsilon_{si} t_{ox}}{\varepsilon_{ox} t_{si}} \beta_s \tan \beta_s$$

and $$\frac{q(V_g - \Delta\phi - V_d)}{2kT} - \ln\left[\frac{2}{t_{si}} \sqrt{\frac{2\varepsilon_{si} kT}{q^2 n_i}} \right] = \ln \beta_d - \ln[\cos \beta_d] + \frac{2\varepsilon_{si} t_{ox}}{\varepsilon_{ox} t_{si}} \beta_d \tan \beta_d$$

UCSD

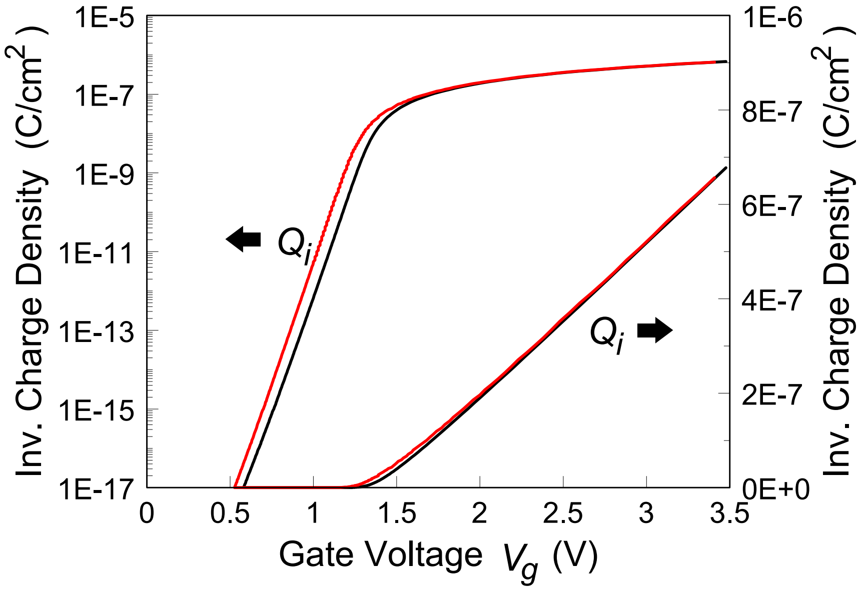
Charge Sheet Model

Key assumption: $$Q_i = \sqrt{2\varepsilon_{si} kTN_a}\left[\sqrt{\frac{q\psi_s}{kT} + \frac{n_i^2}{N_a^2} e^{q(\psi_s - V)/kT}} - \sqrt{\frac{q\psi_s}{kT}}\right]$$

where

$$V_g = V_{fb} + \psi_s - \frac{Q_s}{C_{ox}} = V_{fb} + \psi_s + \frac{\sqrt{2\varepsilon_{si} kTN_a}}{C_{ox}}\left[\frac{q\psi_s}{kT} + \frac{n_i^2}{N_a^2} e^{q(\psi_s - V)/kT}\right]^{1/2}$$

Implicit parameter ψ_s can be eliminated to obtain $Q_i(V_g, V)$.



Example, let V=0, t_{ox}=10nm

Black curves:
$N_a = 10^{17}$cm^{-3}, T=300K

Red curves:
$N_a = 10^{15}$cm^{-3}, T=379K
V_{fb} shifted 0.37V

Inversion-Charge Based Model

Based on the asymptotic behavior of $Q_i(V_g)$ in subthreshold (exponential) and above threshold (linear), then use a fitting function for in between.

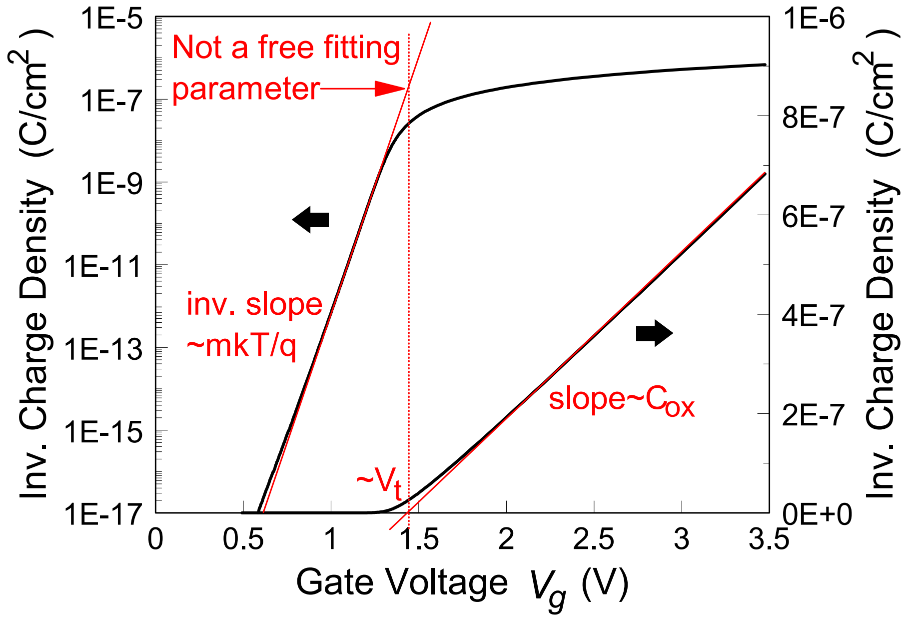
Example: Explicit function,

$$Q_i = \frac{mkT}{q} C_{ox} \ln\left[1 + e^{q(V_g - V_t)/mkT}\right]$$

or Lambert function,

$$\ln\left(\frac{Q_i}{mkTC_{ox}/q}\right) + \frac{Q_i}{mkTC_{ox}/q} = \frac{V_g - V_t}{mkT/q} - \frac{V}{kT/q}$$

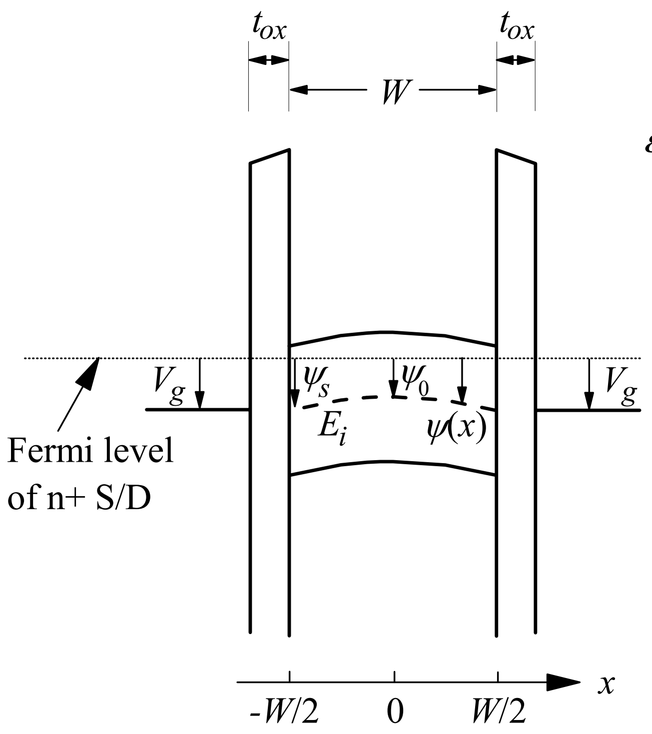
Only 3 fitting parameters: V_t, C_{ox}, mkT/q.
Any multiplier inside or outside the "ln" expression gets absorbed by the other parameters.

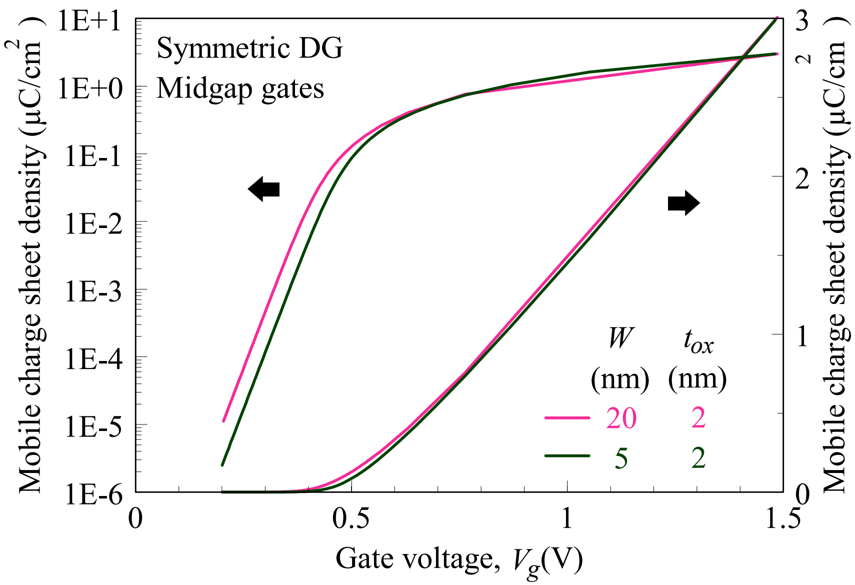


The Symmetric DG MOSFET Case

$$\frac{q(\psi_s-\psi_0)}{2kT} = -\ln\left[\cos\left(\sqrt{\frac{q^2 n_i}{2\varepsilon_{si}kT}}e^{q\psi_0/2kT}(W/2)\right)\right]$$

$$\varepsilon_{ox}\frac{V_g-\Delta\phi_i-\psi_s}{t_{ox}} = \varepsilon_{si}\left.\frac{d\psi}{dx}\right|_{x=W/2} = \frac{Q_i}{2} = \sqrt{2\varepsilon_{si}kTn_i\left(e^{q\psi_s/kT}-e^{q\psi_0/kT}\right)}$$





For two different Si thicknesses, same above threshold characteristics, but different subthreshold characteristics, i.e., cannot be fitted with only three parameters.