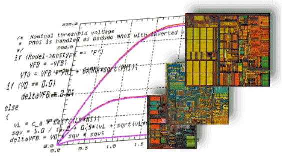


The EKV MOSFET Model v3.0

Gate Current Modeling

Tunneling Mechanism

Intrinsic Gate Current

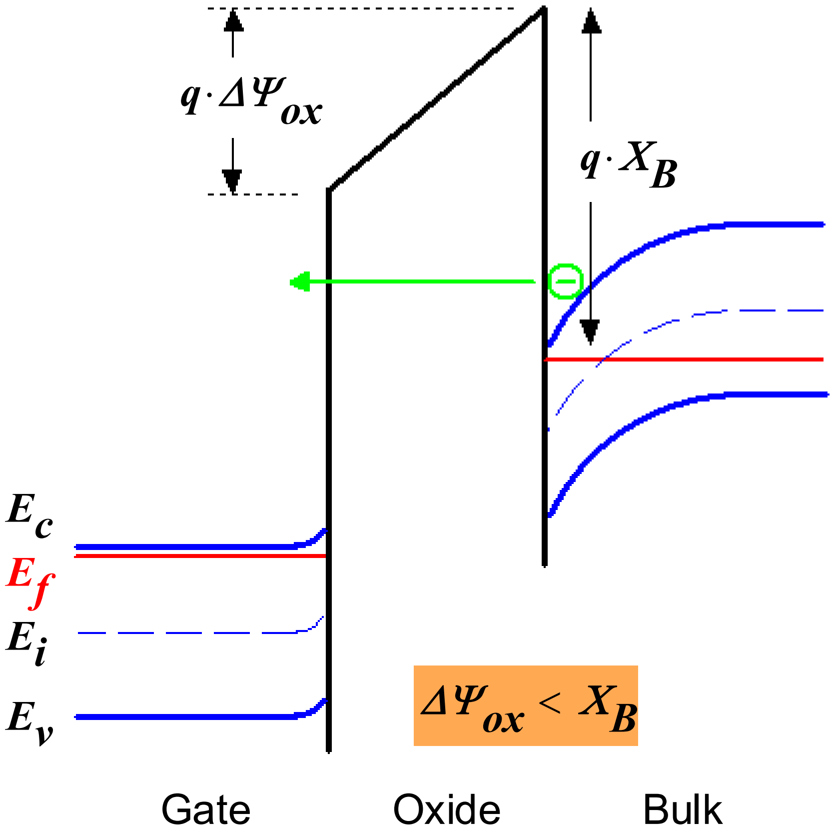
- Intrinsic Gate Current in Inversion
- Gate Current Partitioning
- Gate Current in Accumulation

G/S & G/D Overlap Currents

Total Gate Current

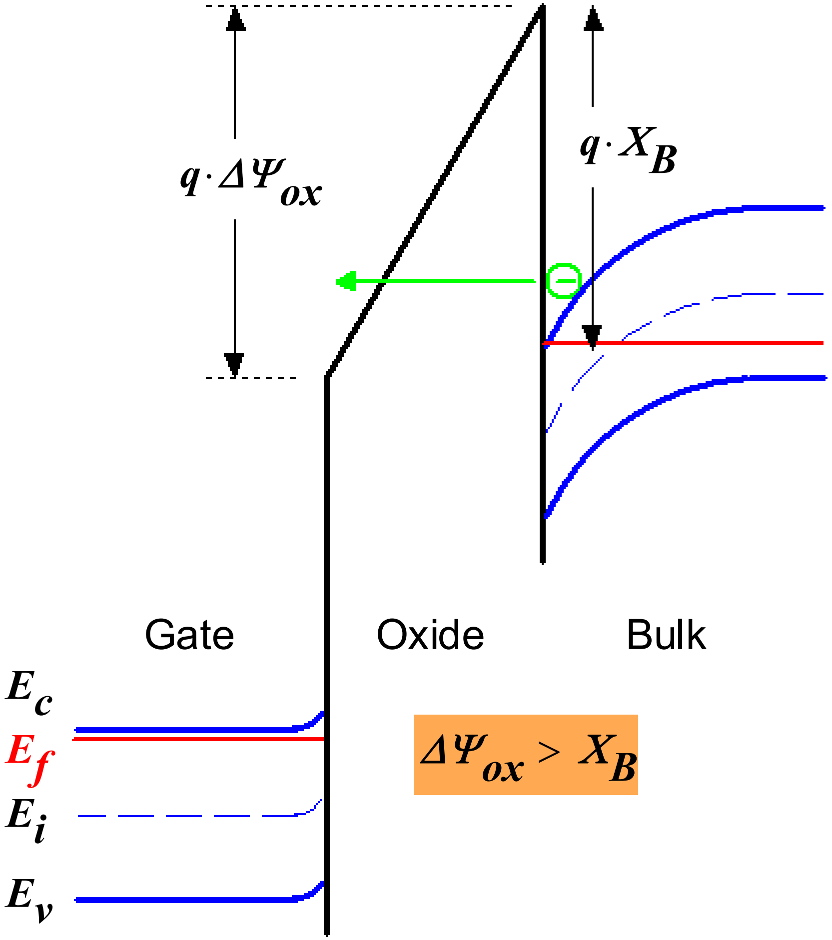
Tunneling Mechanism

Direct Tunneling

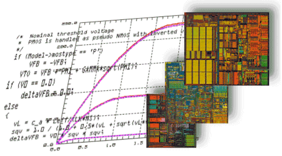


$\Delta\Psi_{ox} < X_B$

Fowler-Nordheim Tunneling



$\Delta\Psi_{ox} > X_B$



Tunneling Mechanism

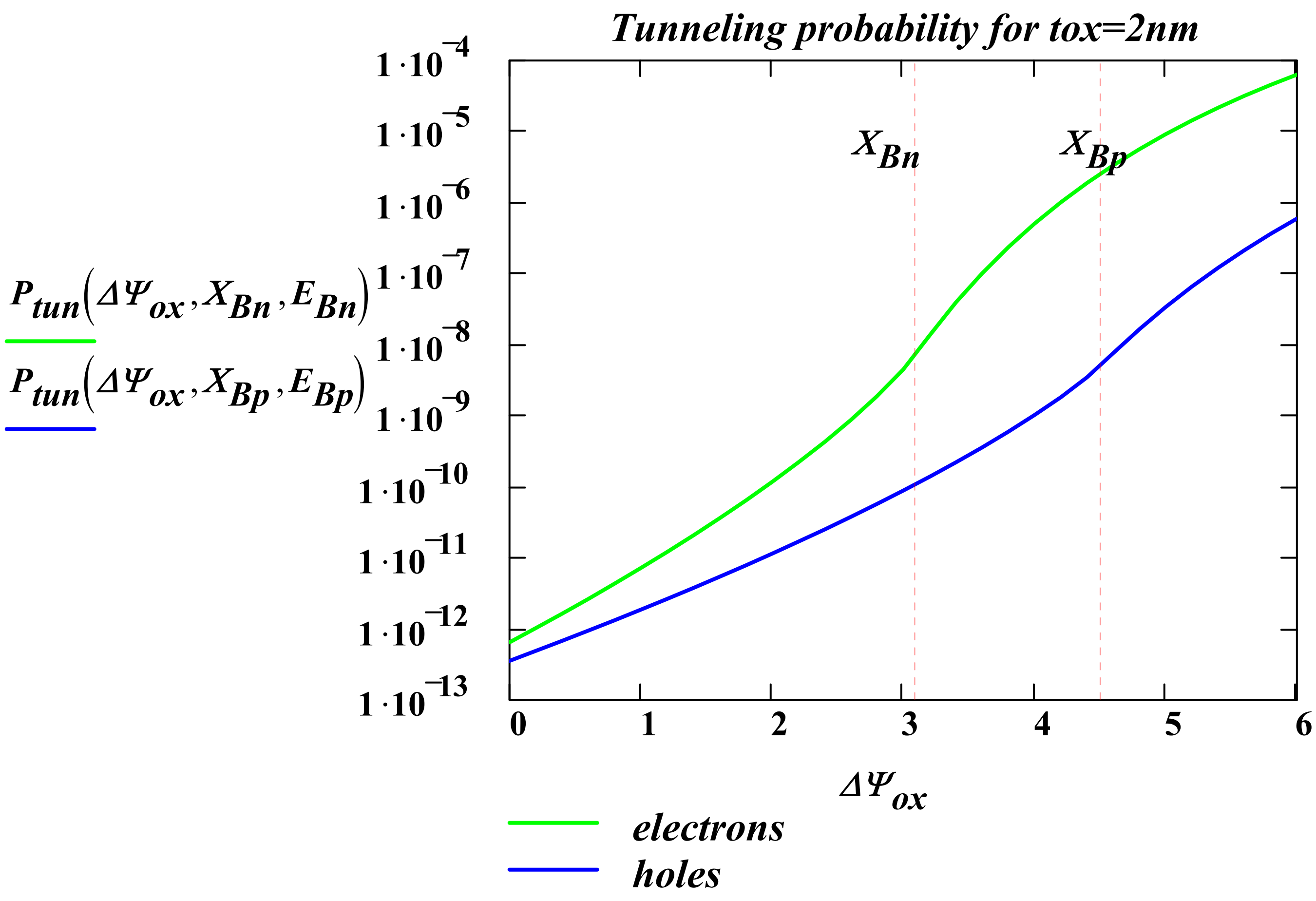
Tunneling Probability

$$P_{tun}\left(\Delta\Psi_{ox}, X_B, E_B\right) = \left| \begin{array}{lll} e^{-\frac{E_B \cdot t_{ox}}{X_B}\cdot\left(\frac{1}{1+\sqrt{1-\frac{\left|\Delta\Psi_{ox}\right|}{X_B}}}+\sqrt{1-\frac{\left|\Delta\Psi_{ox}\right|}{X_B}}\right)} & if \ \left|\Delta\Psi_{ox}\right| < X_B & \text{(direct tunneling)} \\ e^{-\frac{E_B \cdot t_{ox}}{\left|\Delta\Psi_{ox}\right|}} \quad otherwise & & \text{(FN tunneling)} \end{array} \right.$$

where X_B is the Si-SiO$_2$ barrier height and E_B is a characteristic electric field.

Tunneling Mechanism

Tunneling Probability



electrons:

$$X_{Bn} = 3.1\,V$$

$$E_{Bn} = 29\,\frac{V}{nm}$$

holes:

$$X_{Bp} = 4.5\,V$$

$$E_{Bp} = 43\,\frac{V}{nm}$$

Intrinsic Gate Current in Inversion

Gate Current Density :

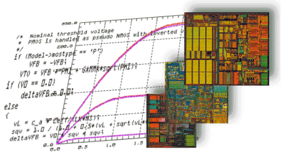
$$J_{gc} = \frac{K_G}{\varepsilon_{ox}} \cdot \frac{\Delta\Psi_{ox}}{t_{ox}} \cdot Q_i \cdot P_{tun}\left(\Delta\Psi_{ox}, X_B, E_B\right) \qquad \left[pA / \mu m^2\right]$$

Voltage Drop across the Oxide :

$$\Delta\Psi_{ox} = \frac{Q_g}{C_{ox}} = \frac{V_G - \Phi_{ms} - \Psi_s}{\frac{1}{2} + \sqrt{\frac{1}{4} + \frac{V_G - \Phi_{ms} - \Psi_s}{\Gamma_g{}^2}}} = \frac{V_G - \Phi_{ms} - \Psi_P + \frac{-Q_i}{n_q \cdot C_{ox}}}{\frac{1}{2} + \sqrt{\frac{1}{4} + \frac{V_G - \Phi_{ms} - \Psi_P + \frac{-Q_i}{n_q \cdot C_{ox}}}{\Gamma_g{}^2}}}$$

- in normalised form :

$$\Delta\psi_{ox} = \frac{v_g - \phi_{ms} - \psi_p + 2 \cdot q}{\frac{1}{2} + \sqrt{\frac{1}{4} + \frac{v_g - \phi_{ms} - \psi_p + 2 \cdot q}{\gamma_g{}^2}}}$$



Intrinsic Gate Current in Inversion

Total Intrinsic Gate Current :

$$I_{GC} = W\int_0^L J_{gc}\,dx = I_{G0}\cdot\int_0^1 q\cdot\Delta\psi_{ox}\cdot P_{tun}\,d\xi$$

with $I_{G0} = 2\cdot n_q\cdot K_G\cdot\frac{W\cdot L}{{t_{ox}}^2}\cdot {U_T}^2$ and $\xi = \frac{x}{L}$

- linear expansion of $q\cdot\delta\psi_{ox}$ and P_{tun} around $\xi = 0$, then integrate over ξ :

$$\frac{I_{GC}}{I_{G0}} = i_{GC} \approx i_{go}\cdot\int_0^1 (1+a\cdot\xi)\cdot e^{b\cdot\xi}\,d\xi \approx i_{go}\cdot\frac{2+a}{2-b}$$

where i_{go} , a and b are evaluated at source $(q = q_s)$:

$$i_{go} = q_s\cdot\Delta\psi_{ox}\cdot P_{tun} \qquad a = \frac{dq}{d\xi}\cdot\left(\frac{1}{q}+\frac{1}{\Delta\psi_{ox}}\cdot\frac{d\Delta\psi_{ox}}{dq}\right) \qquad b = \frac{d}{d\xi}ln(P_{tun}(\xi))$$

Intrinsic Gate Current in Inversion

Current Partitioning

- Gate-to-channel current I_{GC} is to be partitioned into gate-to-source and gate-to-drain currents I_{GS} and I_{GD}, respectively
- 1st-order perturbation approximation :
  charge distribution along the channel is not changed significantly by the gate current

$$I_{GS} = W\cdot\int_0^L \left(1-\frac{x}{L}\right)\cdot J_{gc}\,dx \qquad\qquad I_{GD} = W\cdot\int_0^L \frac{x}{L}\cdot J_{gc}\,dx$$

- then :

$$\frac{I_{GS}}{I_{G0}} = i_{GS} \approx i_{go}\cdot\int_0^1 (1-\xi)\cdot(1+a\cdot\xi)\cdot e^{b\cdot\xi}\,d\xi \approx \frac{i_{go}}{2}\cdot\frac{3+a}{3-b}$$

$$\frac{I_{GD}}{I_{G0}} = i_{GD} = i_{GC} - i_{GS}$$

EKV3.0: Gate Current Modeling

Intrinsic Gate Current in Accumulation

NMOS :

- N+ gate: accumulation layer of electrons
- P- bulk: accumulation layer of holes

PMOS :

- P+ gate: accumulation layer of holes
- N- bulk: accumulation layer of electrons

Oxide energy barrier is higher for holes than for electrons ⇒ electron tunneling is dominant

NMOS:

$$J_{gb} = \frac{K_G}{\varepsilon_{ox}} \cdot \frac{\Psi_{ox}}{t_{ox}} \cdot {\color{red}Q_g} \cdot P_{tun}\left(\Delta\Psi_{ox}, X_B, E_B\right)$$

$$Q_g = \frac{\varepsilon_{ox}}{t_{ox}} \cdot \Delta\Psi_{ox}$$

$$I_{GB} = -K_G \cdot \frac{W \cdot L}{t_{ox}^{\;2}} \cdot \Delta\Psi_{ox}^{\;2} \cdot P_{tun}$$

PMOS:

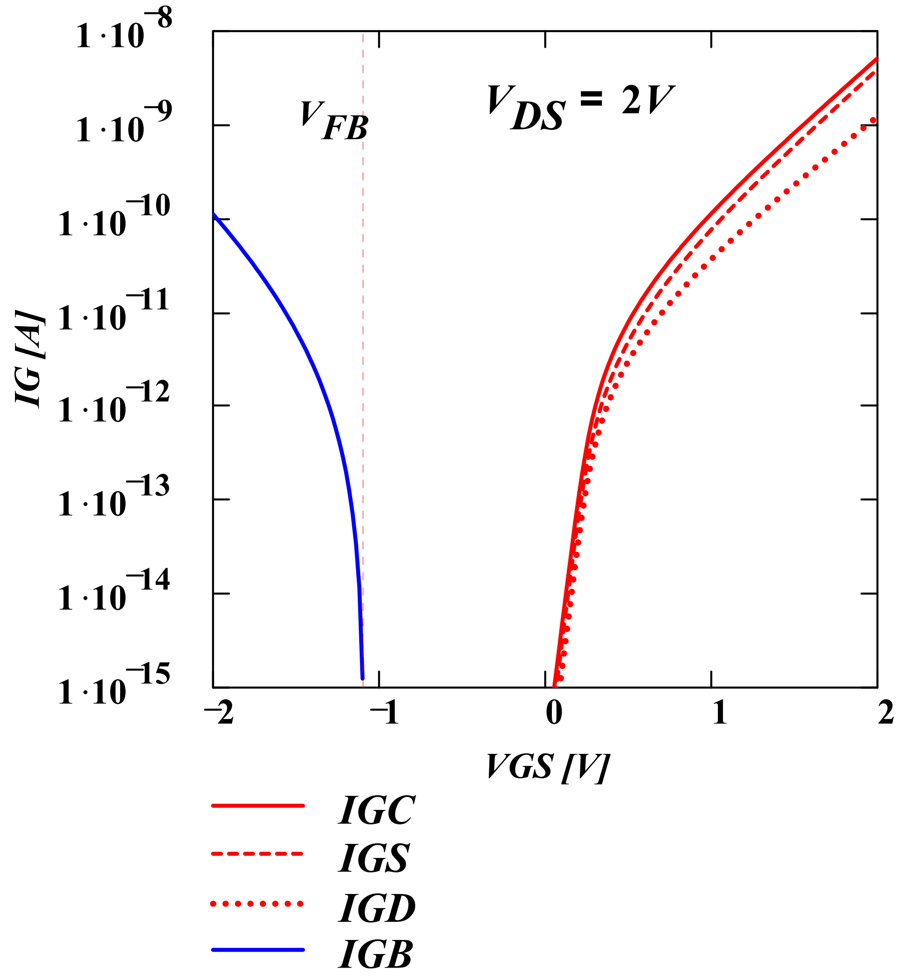
$$J_{gb} = \frac{K_G}{\varepsilon_{ox}} \cdot \frac{\Psi_{ox}}{t_{ox}} \cdot \left(-{\color{red}Q_b}\right) \cdot P_{tun}\left(\Delta\Psi_{ox}, X_B, E_B\right)$$

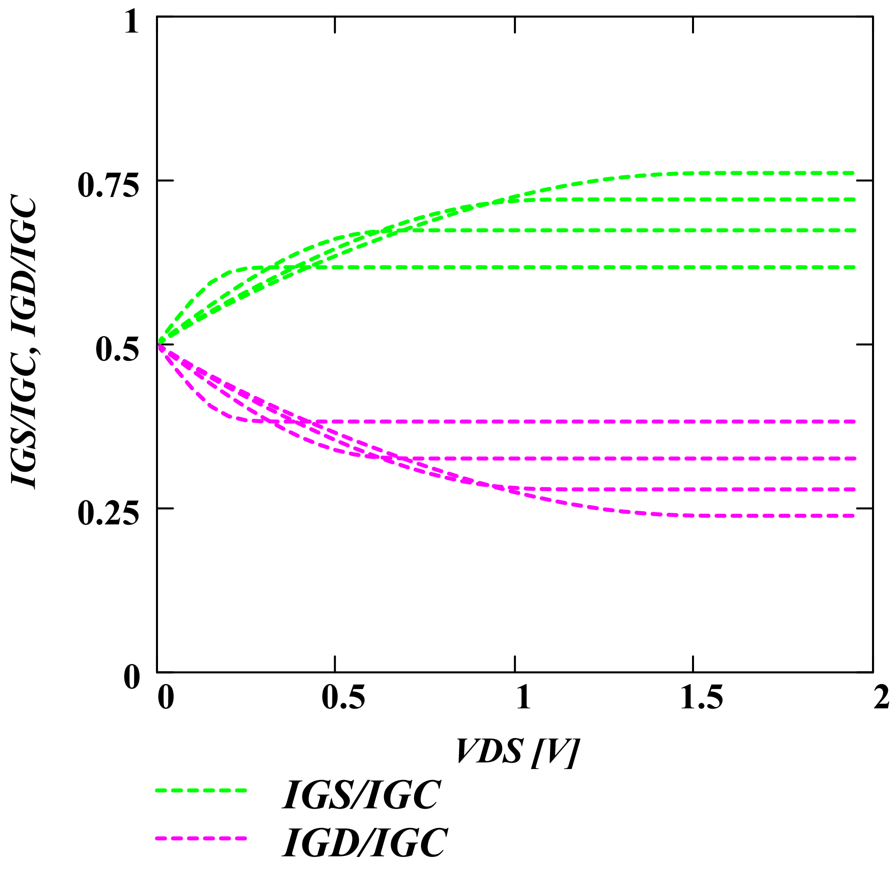
$$-Q_b = Q_g + Q_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \cdot \Delta\Psi_{ox} + Q_{ox}$$

$$I_{GB} = -K_G \cdot \frac{W \cdot L}{t_{ox}^{\;2}} \cdot \Delta\Psi_{ox} \cdot \left(\Delta\Psi_{ox} + \frac{Q_{ox}}{C_{ox}}\right) \cdot P_{tun}$$

Intrinsic Gate Currents

$W = 10\,\mu m$ $L = 0.6\,\mu m$ $t_{ox} = 2\,nm$ $\Gamma_b = 0.39\sqrt{V}$ $\Gamma_g = 5.0\sqrt{V}$





EKV3.0: Gate Current Modeling

Source/Gate & Drain/Gate Overlap Currents 1/2

S/G & D/G Overlap Simplified Characteristics :

- D/G & S/G flatband voltage : $V_{FB.ov}$
- D/G & S/G equivalent oxide thickness : $t_{ox.ov}$
- polysilicon gate modulation factor : $\Gamma_{g.ov} = \sqrt{2 \cdot q \cdot \varepsilon_{si} \cdot N_g} \cdot \frac{t_{ox.ov}}{\varepsilon_{ox}}$
- D & S diffusion modulation factor : $\Gamma_{s.ov} = \Gamma_{d.ov} = \sqrt{2 \cdot q \cdot \varepsilon_{si} \cdot N_{LDD}} \cdot \frac{t_{ox.ov}}{\varepsilon_{ox}}$

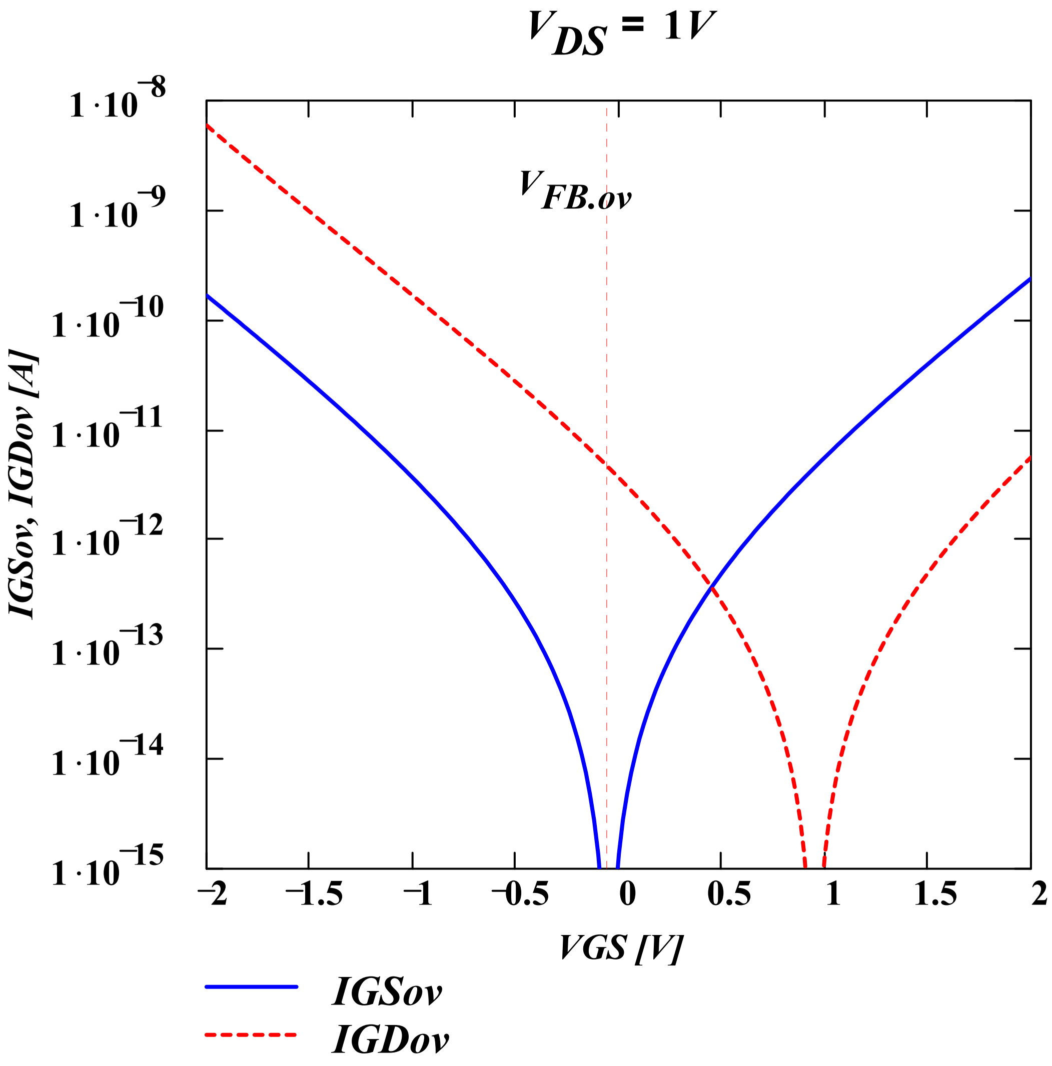
$$\Delta\Psi_{ox.ov}(V_{GS}) = \begin{cases} \dfrac{V_{GS} - V_{FB.ov}}{\dfrac{1}{2} + \sqrt{\dfrac{1}{4} + \dfrac{V_{GS} - V_{FB.ov}}{\Gamma_{g.ov}^{2}}}} & if \;\; V_{GS} > V_{FB.ov} \\[2ex] \dfrac{V_{GS} - V_{FB.ov}}{\dfrac{1}{2} + \sqrt{\dfrac{1}{4} + \dfrac{V_{FB.ov} - V_{GS}}{\Gamma_{s.ov}^{2}}}} & otherwise \end{cases}$$

depletion at gate &
accumulation at source

accumulation at gate &
depletion at source

EKV3.0: Gate Current Modeling

Source/Gate & Drain/Gate Overlap Currents



$t_{ox.ov} = 2\,nm$

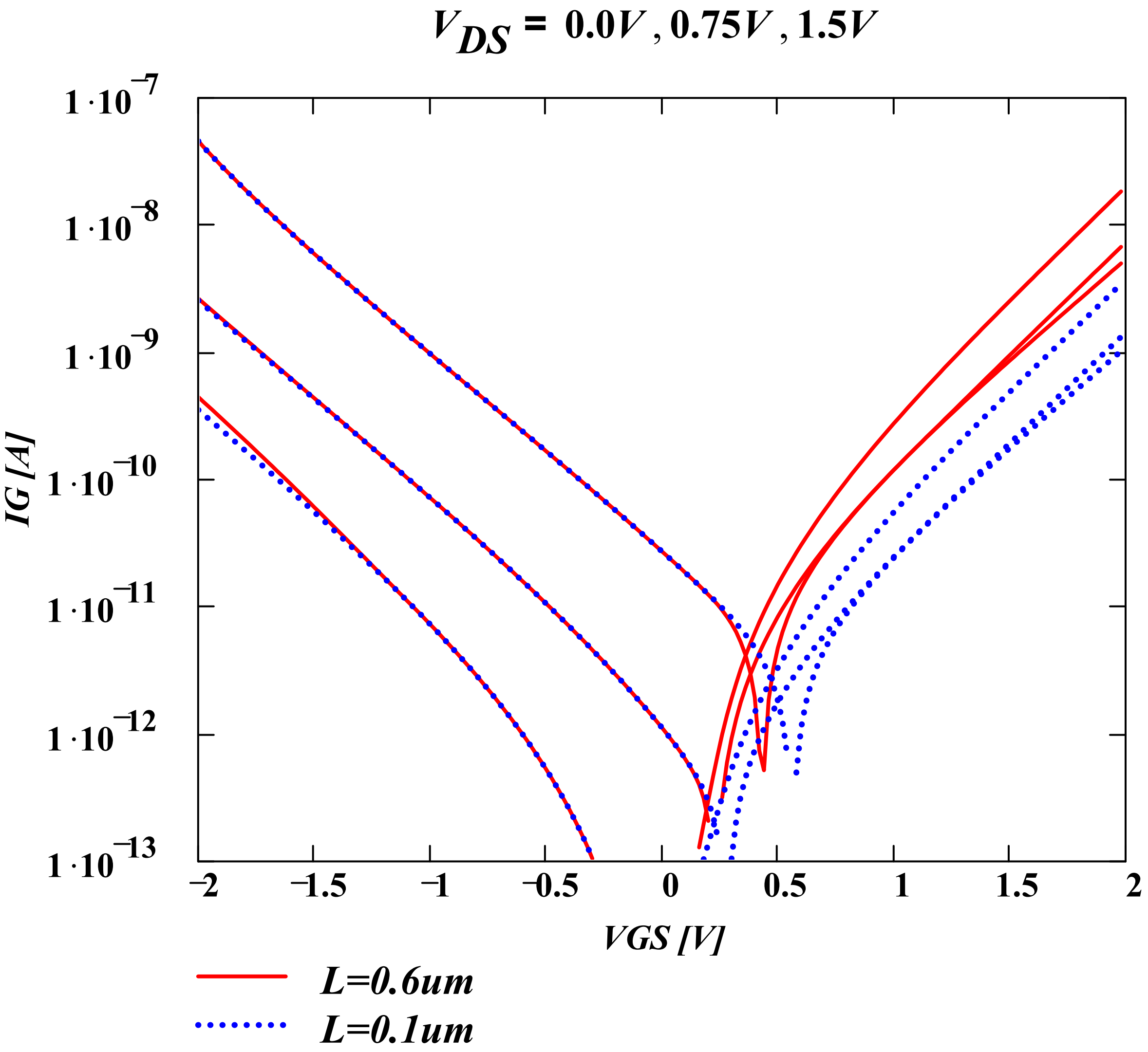
$W = 10\,\mu m$

$L_{ov} = 10\,nm$

$\Gamma_{s.ov} = 5.0\sqrt{V}$

$\Gamma_{g.ov} = 5.0\sqrt{V}$

Total Gate Current



$t_{ox.ov} = 2\,nm$

$W = 10\,\mu m$

$L_{ov} = 10\,nm$