EE-612:
Lecture 16:
2D Electrostatics: Part 2

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outline

1) Quick review
2) Geometric screening length
3) Discussion

effective doping

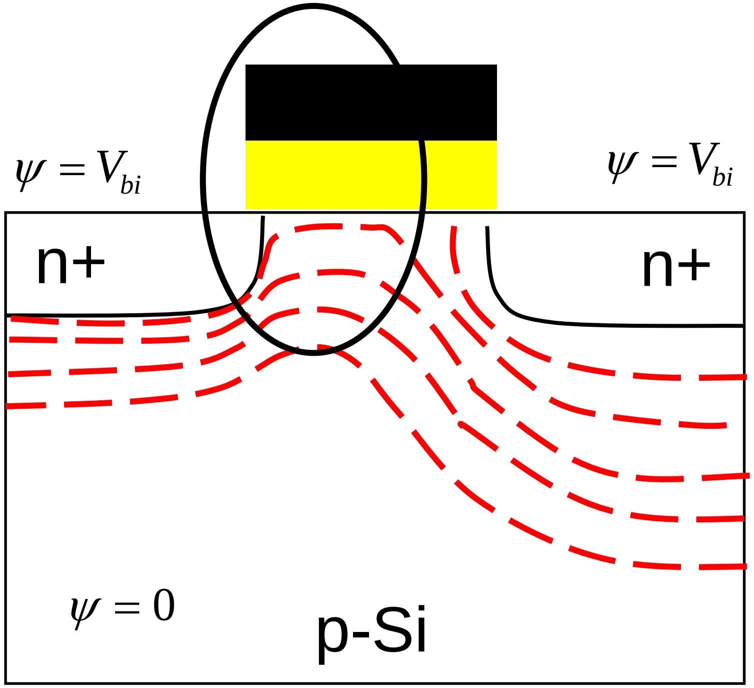
$$\frac{\partial^2 \psi}{\partial x^2} = \frac{qN_A}{\varepsilon_{Si}} - \frac{\partial^2 \psi}{\partial y^2}$$

$$\frac{\partial^2 \psi}{\partial x^2} = \frac{q\, N_A\big|_{eff}}{\varepsilon_{Si}}$$

$$N_A\big|_{eff} < N_A$$

2D electrostatics ‘effectively’ lowers the channel doping density

potential contours



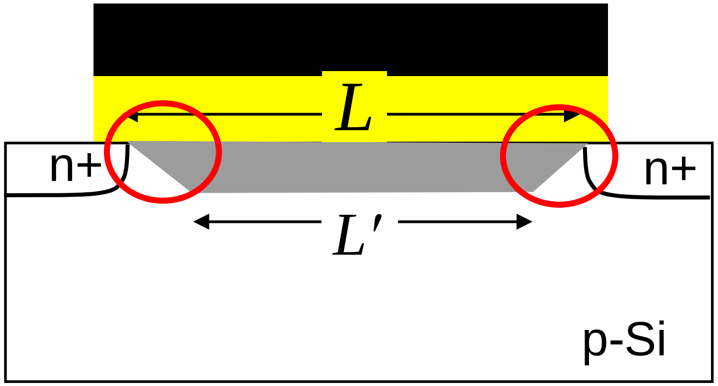
Need:

$t_{ox} << L,$

$x_j < L,$

$W_{DM} << L$

charge sharing model



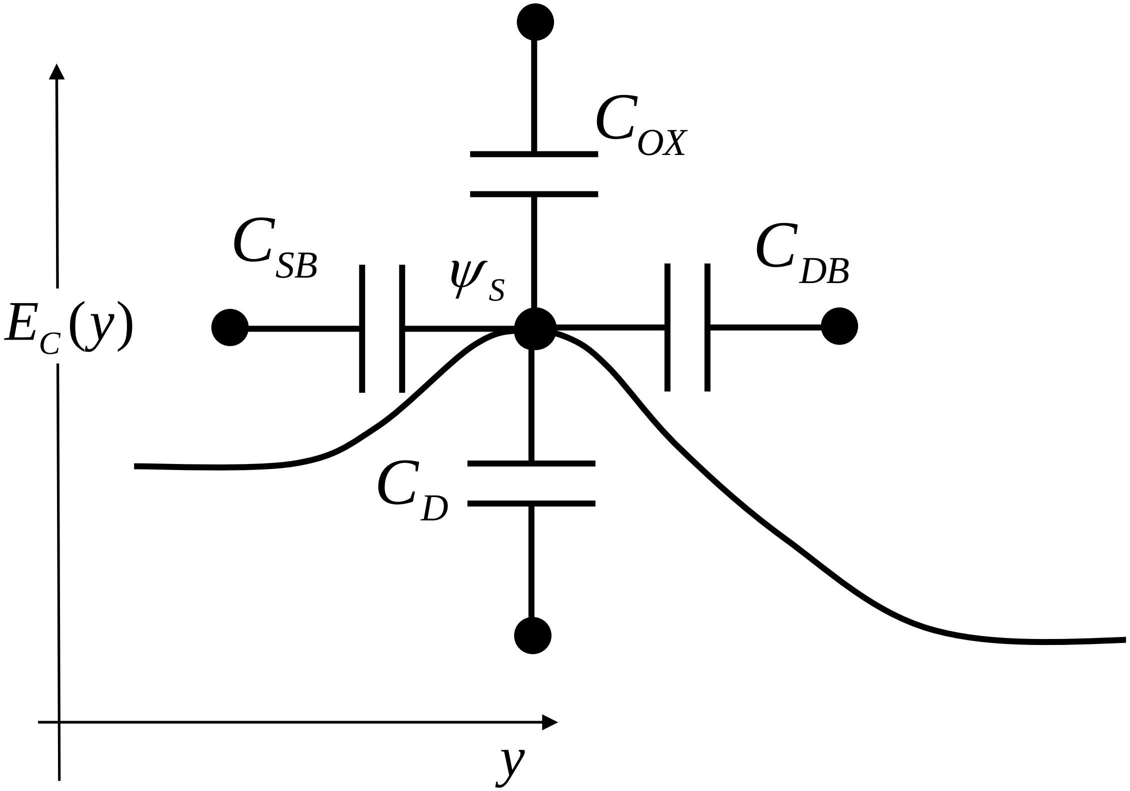
Need:

$x_j < L$,

$W_{DM} < x_j$

$$\gamma = \frac{L + L'}{2L} = 1 - \frac{x_j}{L}\left(\sqrt{1 + \frac{2W_{DM}}{x_j}} - 1\right)$$

capacitor model



$$S = 2.3m\left(k_BT/q\right)$$

$$m = C_\Sigma / C_{OX}$$

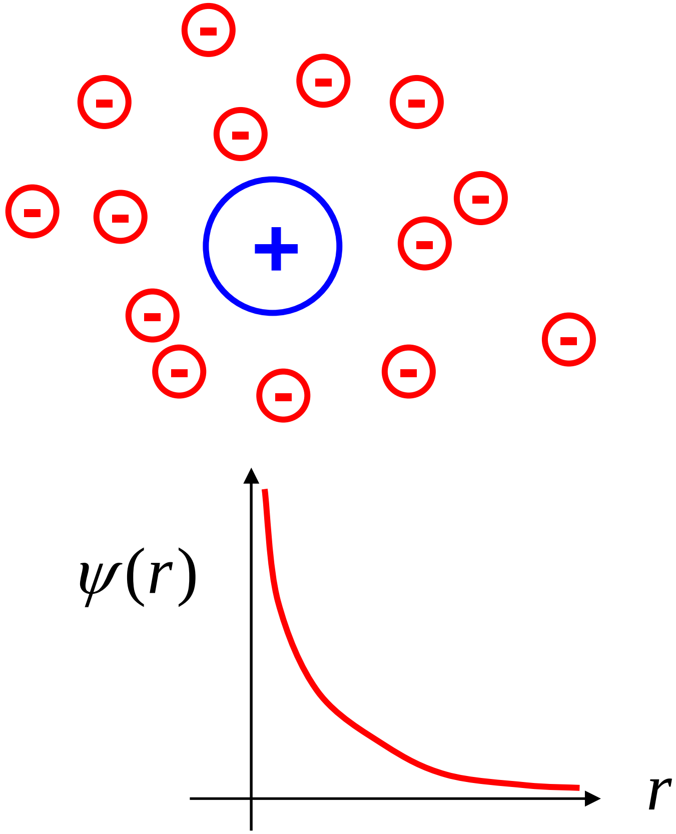
$$DIBL = C_{DB}/C_{OX}$$

Need: $t_{OX} \ll L$

outline

1) Quick review
2) **Geometric screening length**
3) Discussion

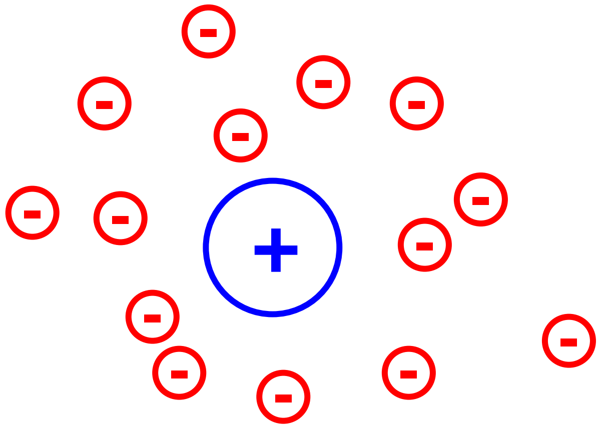
screening

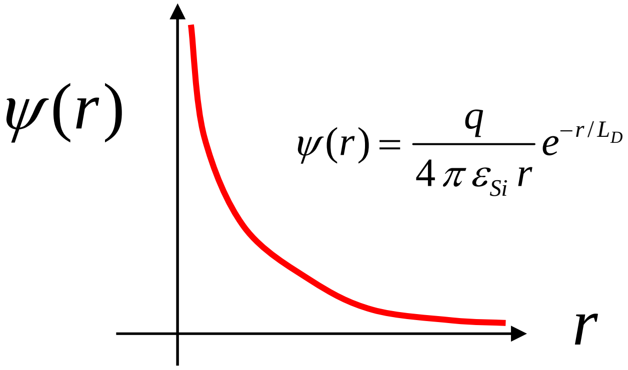


$$\psi(r) = \frac{q}{4\pi\varepsilon_{Si}\,r}e^{-r/L_D}$$

$$L_D = \sqrt{\frac{\varepsilon_{Si}k_BT}{q^2N_D}}$$

screening





$$\psi(r) = \frac{q}{4\pi\varepsilon_{Si}r}e^{-r/L_D}$$

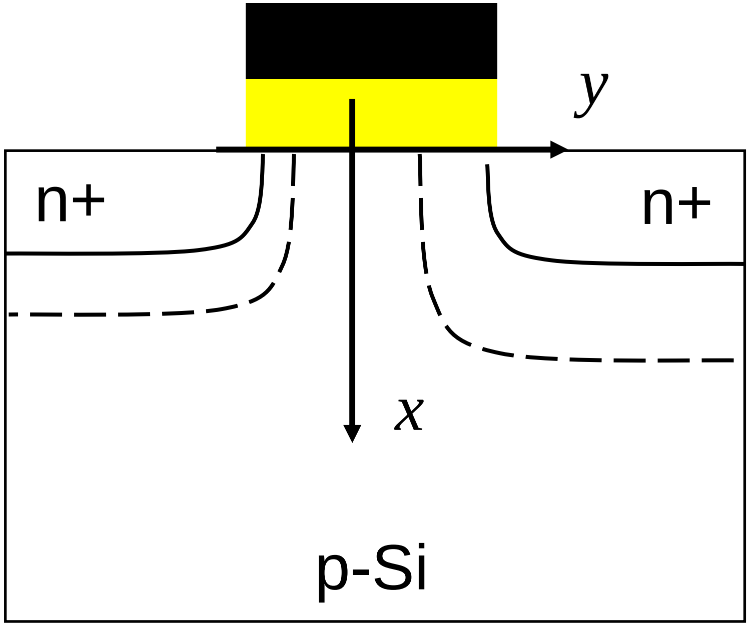
$$\frac{d^2\psi}{dx^2} = \frac{-\rho}{\varepsilon_{Si}} = \frac{q\left(n-n_0\right)}{\varepsilon_{Si}}$$

$$n = n_0 e^{q\psi/k_BT} \approx n_0(1+q\psi/k_BT)$$

$$\frac{d^2\psi}{dx^2} = \frac{q^2 n_0}{\varepsilon_{Si}k_B T}\psi = \frac{\psi}{L_D^2}$$

$$\boxed{\frac{d^2\psi}{dx^2} - \frac{\psi}{L_D^2} = 0}$$

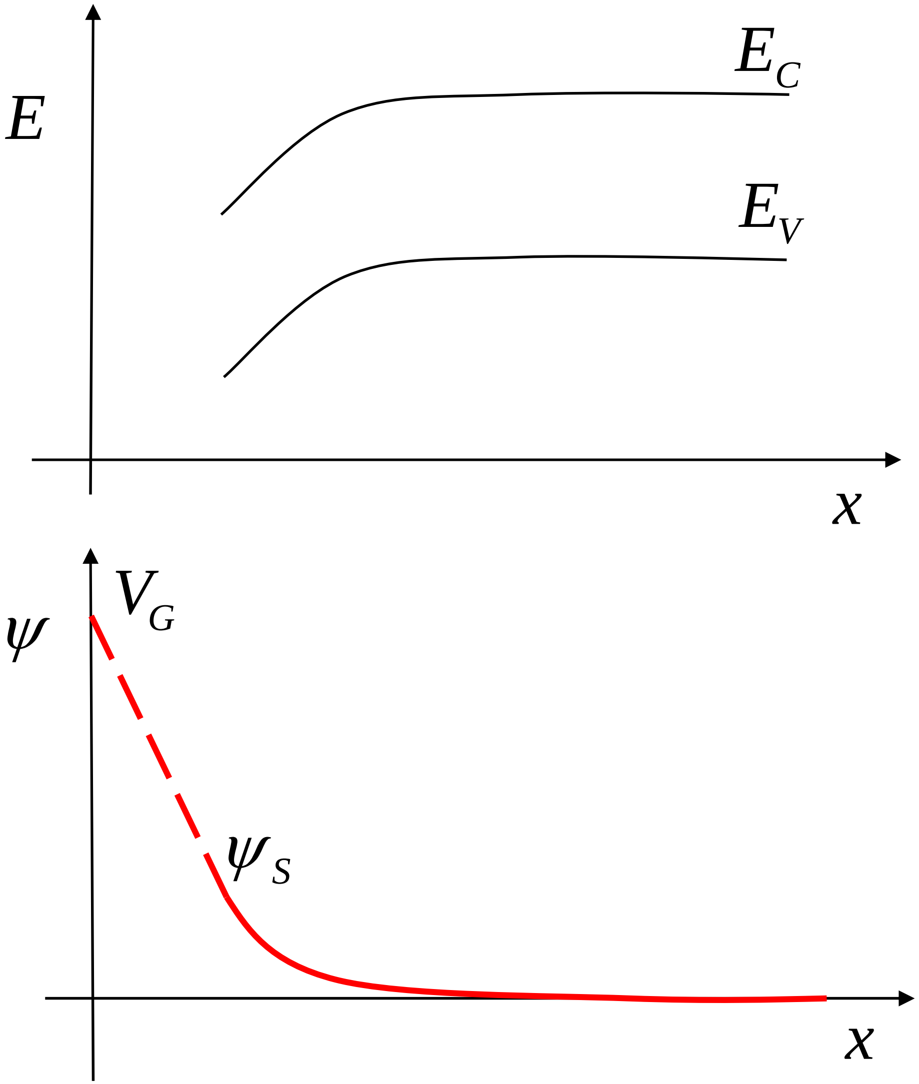
geometric scaling length



$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = \frac{qN_A}{\varepsilon_{Si}} \quad (\text{below}\, V_T)$$

‘convert’ this to a 1D equation

geometric scaling length (ii)



1D:

$$\left.\begin{aligned} \frac{\partial^2 \psi}{\partial x^2} &= \frac{qN_A}{\varepsilon_{Si}} \\ \frac{\partial^2 \psi}{\partial x^2} &\approx \frac{\left(V_G - \psi_S\right)}{\Lambda^2} \end{aligned}\right\}$$

$$\Lambda = ?$$

geometric scaling length (v)

$$\Lambda_{BULK} \approx \sqrt{\frac{\varepsilon_{Si}}{\varepsilon_{OX}} W_{DM} t_{OX}}$$

$$\Lambda_{SOI} \approx \sqrt{\frac{\varepsilon_{Si}}{\varepsilon_{OX}} t_{Si} t_{OX}} < \Lambda_{BULK}$$

$$\Lambda_{DG\ SOI} \approx \sqrt{\frac{\varepsilon_{Si}}{2\varepsilon_{OX}} t_{Si} t_{OX}} < \Lambda_{SOI}$$

$$\Lambda_{CYL} < \Lambda_{DG\ SOI}$$

see:
D.J. Frank, Y. Taur, and H.S.P. Wong, 'Generalized scale length for 2D Effects in MOSFETs," *IEEE EDL*, **19**, p. 385, 1998.

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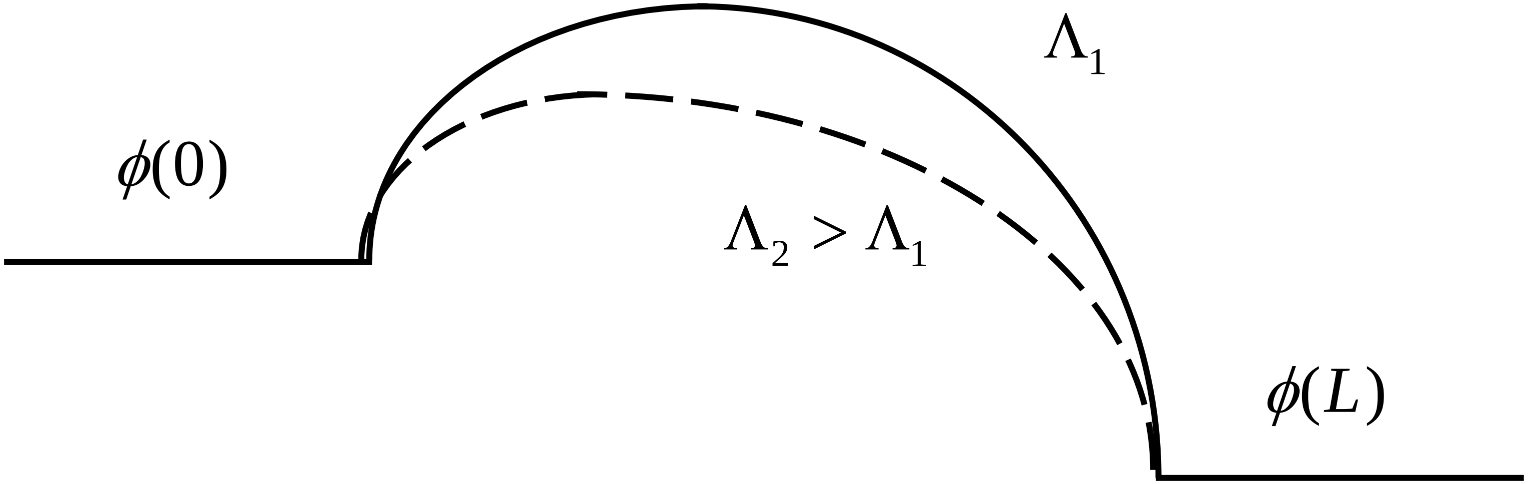
geometric scaling length (vii)

$$\frac{d^2\phi}{dy^2} - \frac{\phi}{\Lambda^2} = 0$$

$L >> \Lambda$ (long channel)

$L \approx (1.5 - 2)\Lambda$ (typical)



$$\phi(y) = A\cosh(y/\Lambda) + B\sinh(y/\Lambda)$$

analytical solutions

$$\Delta V_T \approx 8(m-1)\sqrt{V_{bi}(V_{bi}+V_{DS})}e^{-L/\lambda}$$

$$\left(x_j \geq W_{DM}\right)$$

$$S \approx \frac{2.3mk_BT}{q}\left(1+\frac{11t_{ox}}{W_{DM}}e^{-L/\lambda}\right)$$

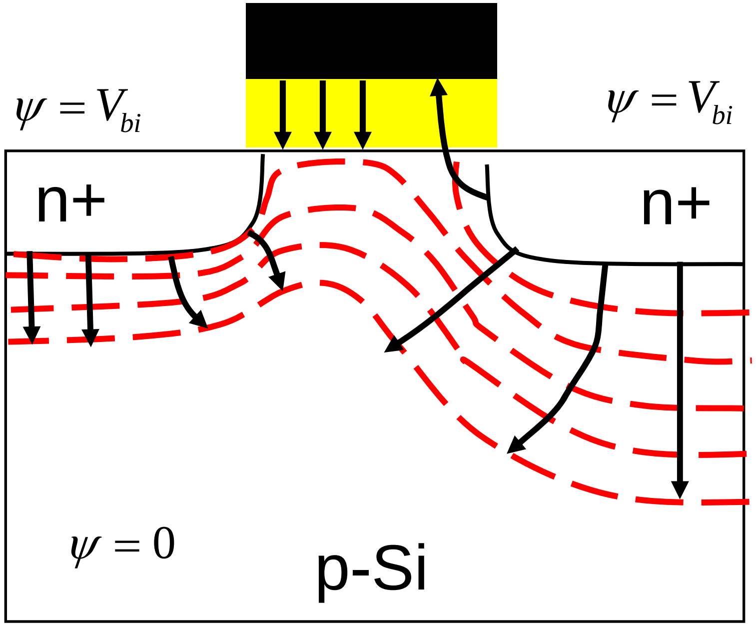
$$\lambda = 2mW_{DM}/\pi$$

See Taur and Ning, Appendix 6

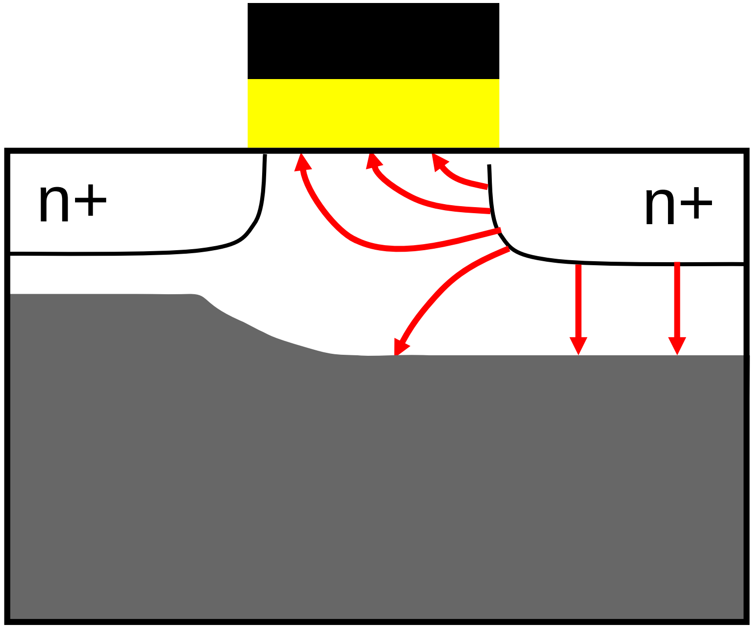
outline

1) Quick review
2) Geometric scaling length
3) **Discussion**

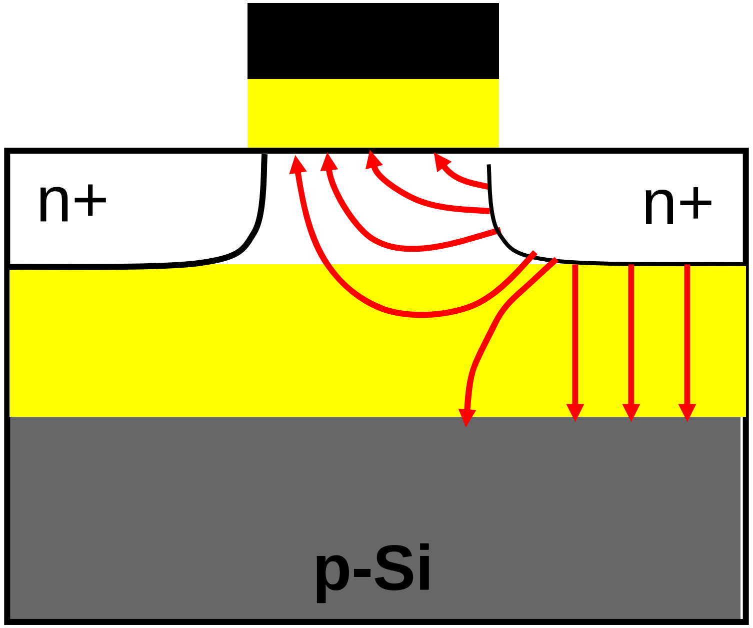
field lines



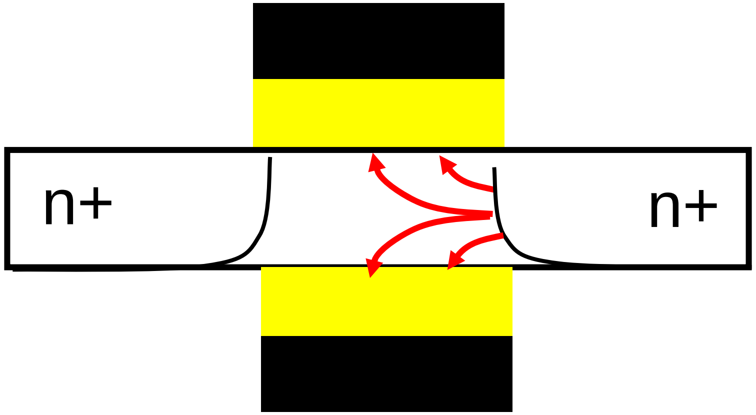
field lines (bulk)



field lines (SOI)



field lines (SOI)

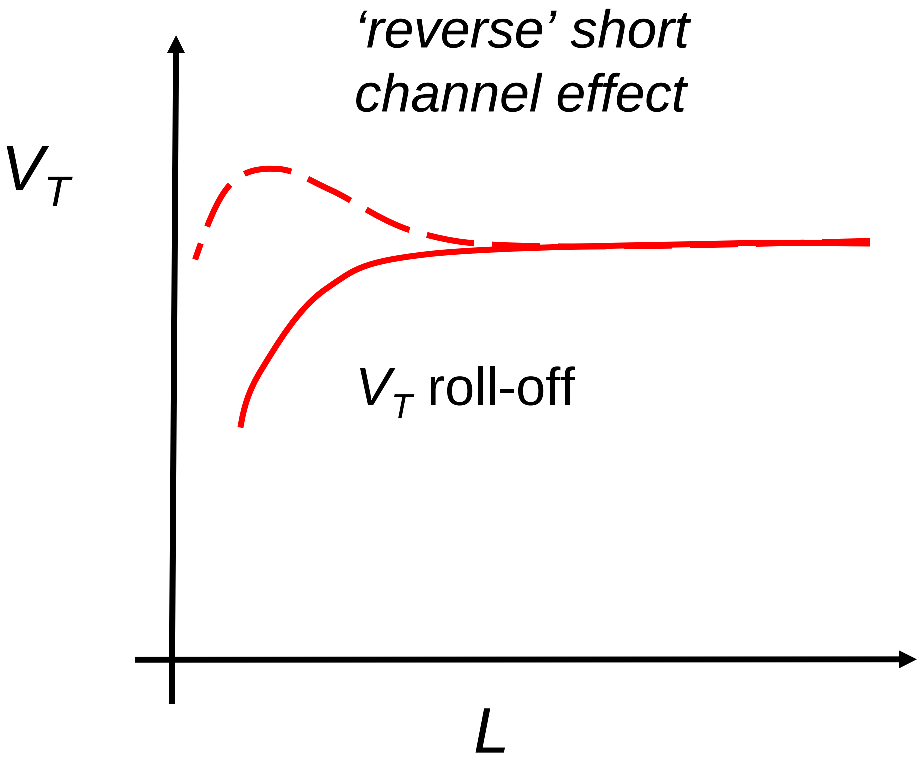


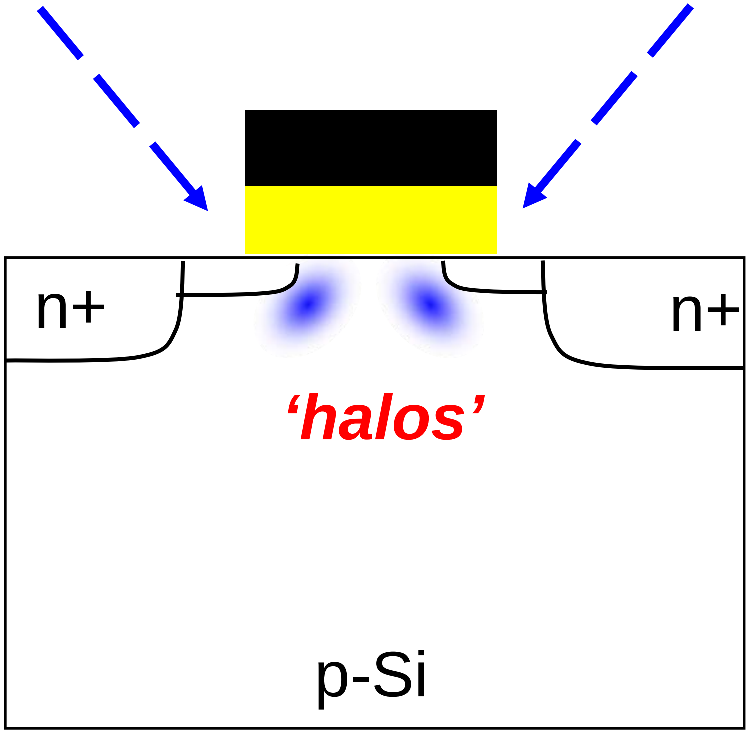
‘gate all around’

FINFET

tri-gate

reverse short channel effect





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