

EE-612: Lecture 1 1D MOS Electrostatics

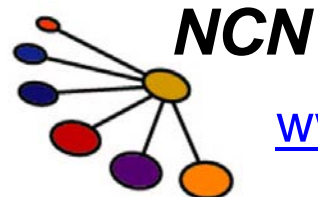
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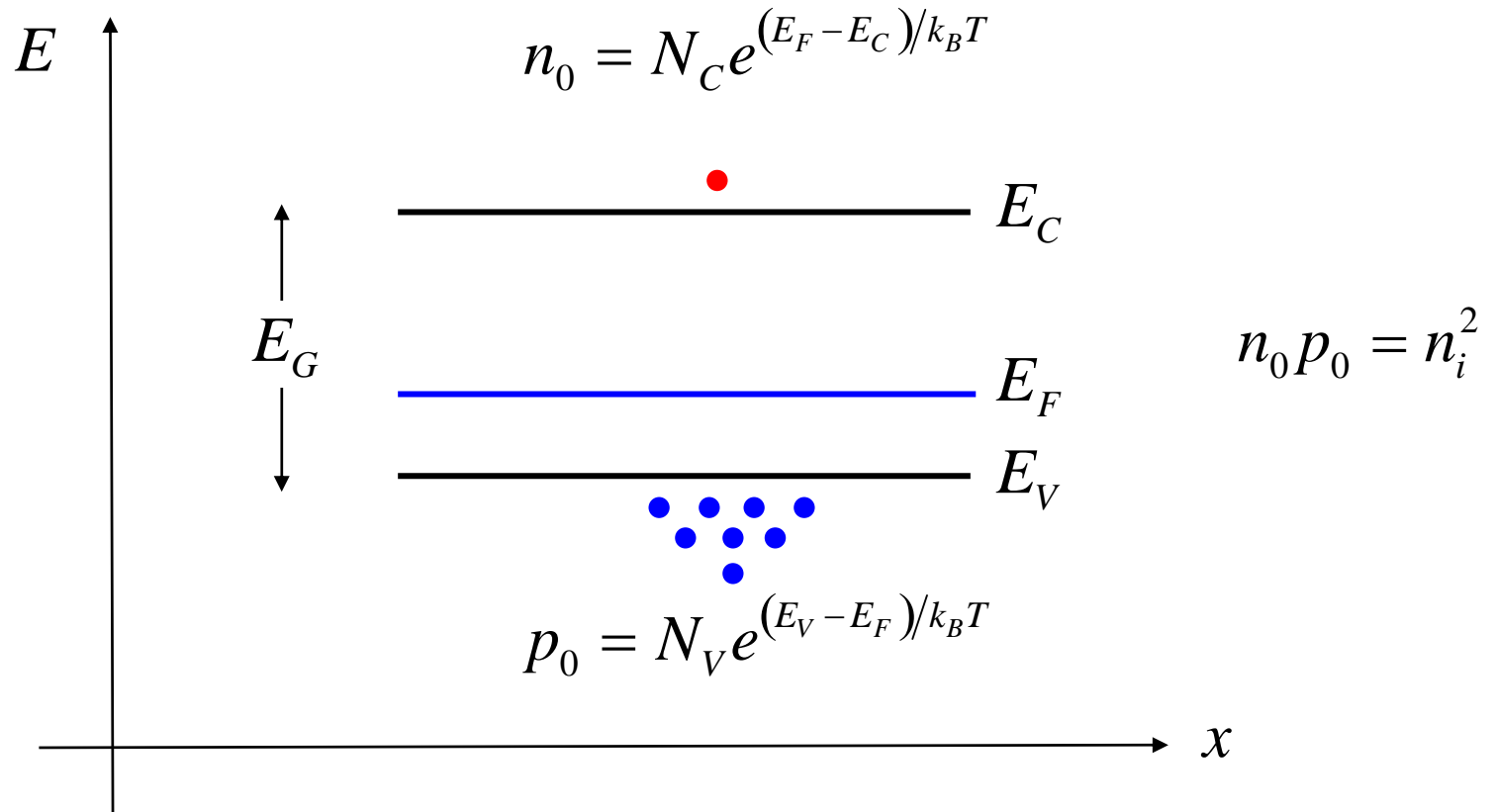


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outline

- 1) Review of some fundamentals
- 2) Identify next steps

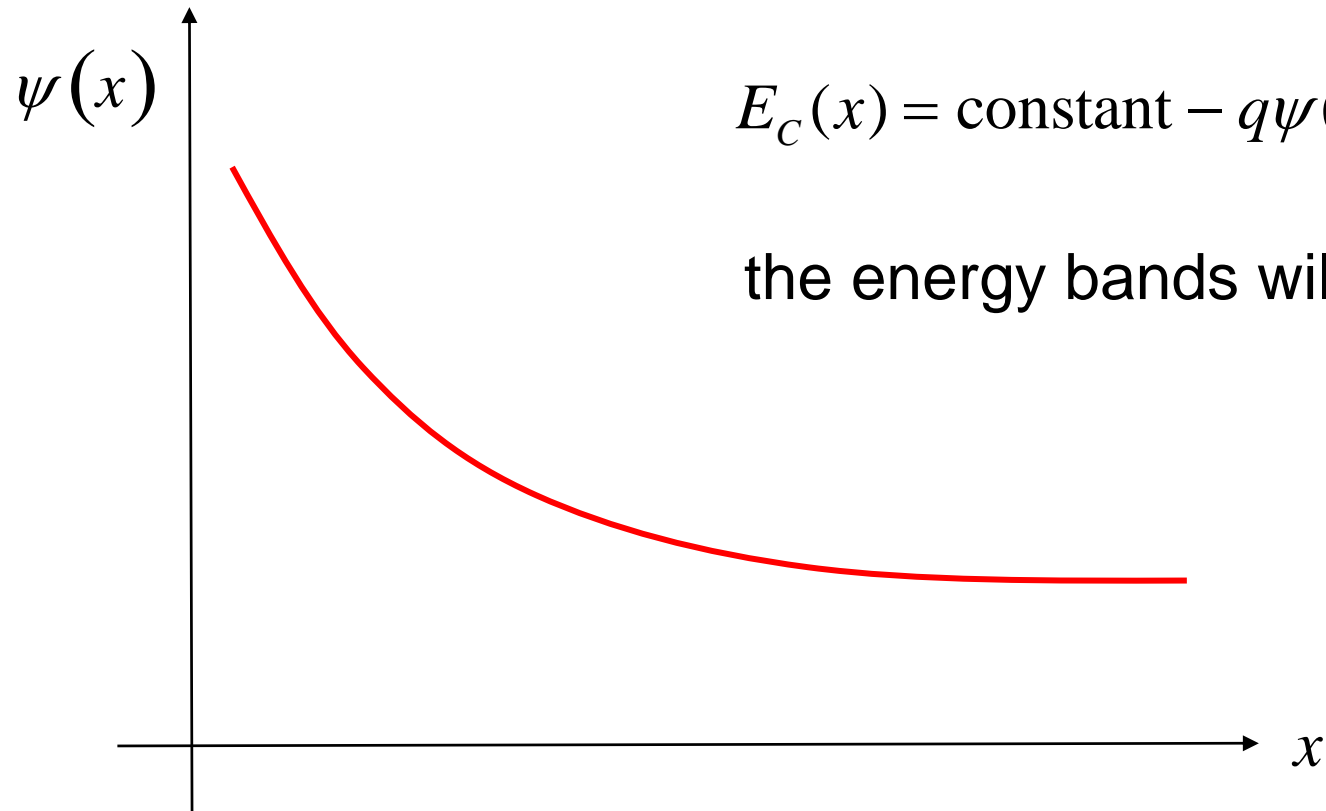
energy bands



Assumptions:

- i) equilibrium, ii) Boltzmann carrier statistics, iii) uniform electrostatic potential

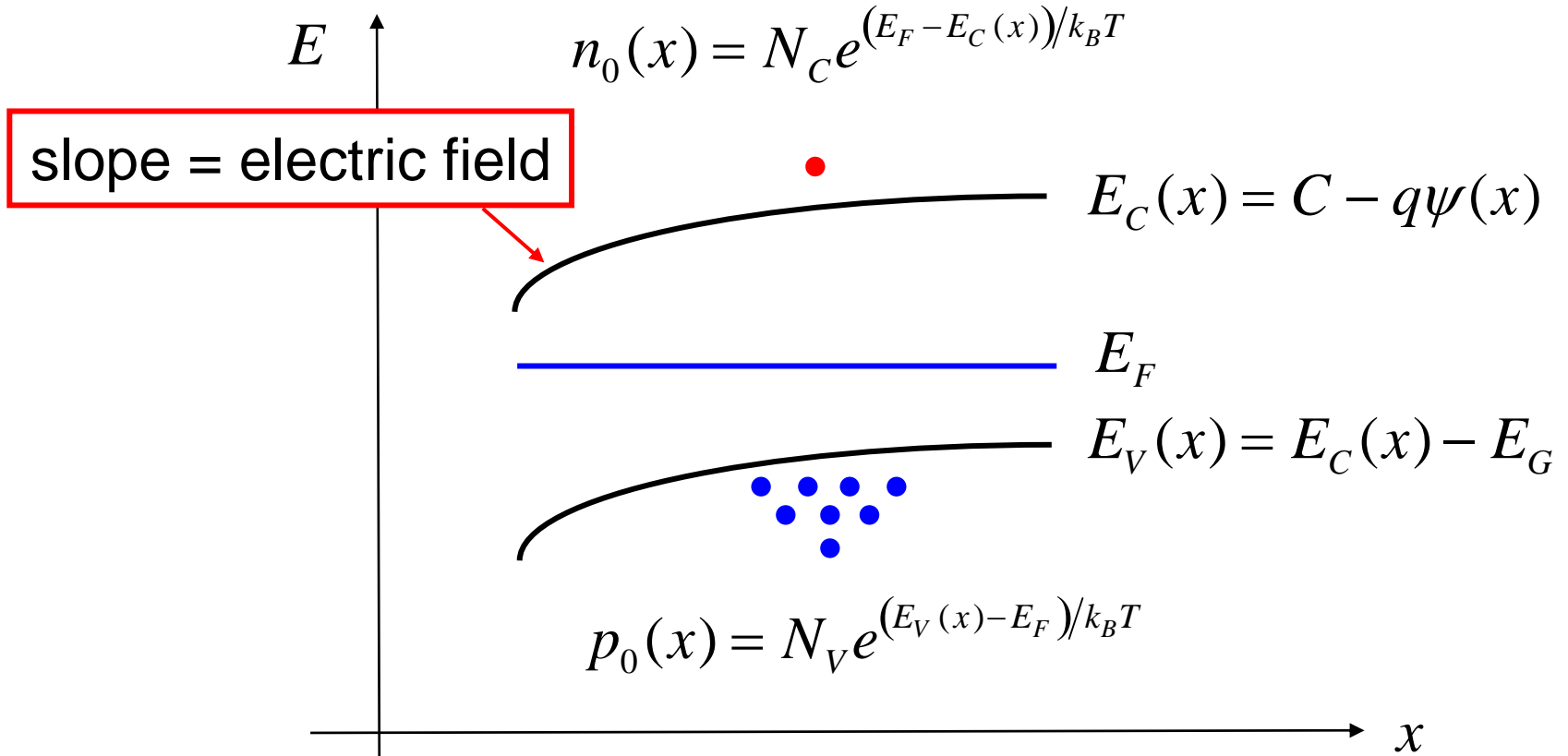
electrostatic potential



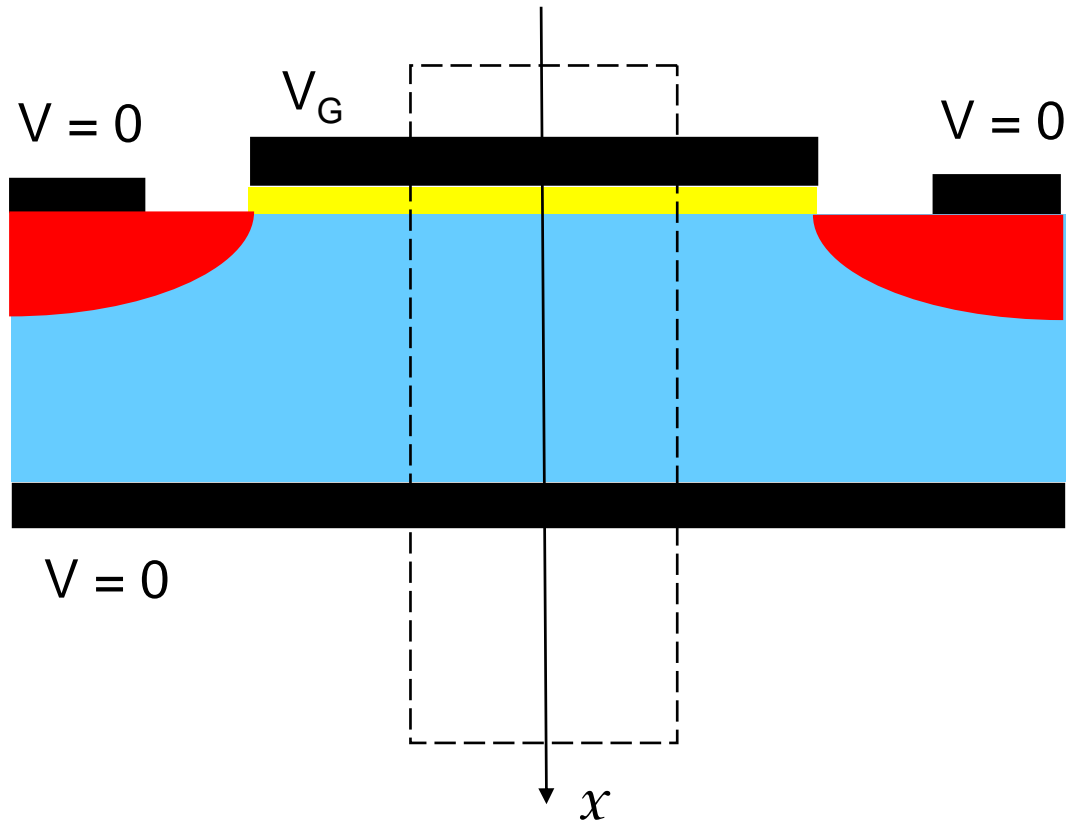
$$E_C(x) = \text{constant} - q\psi(x)$$

the energy bands will bend

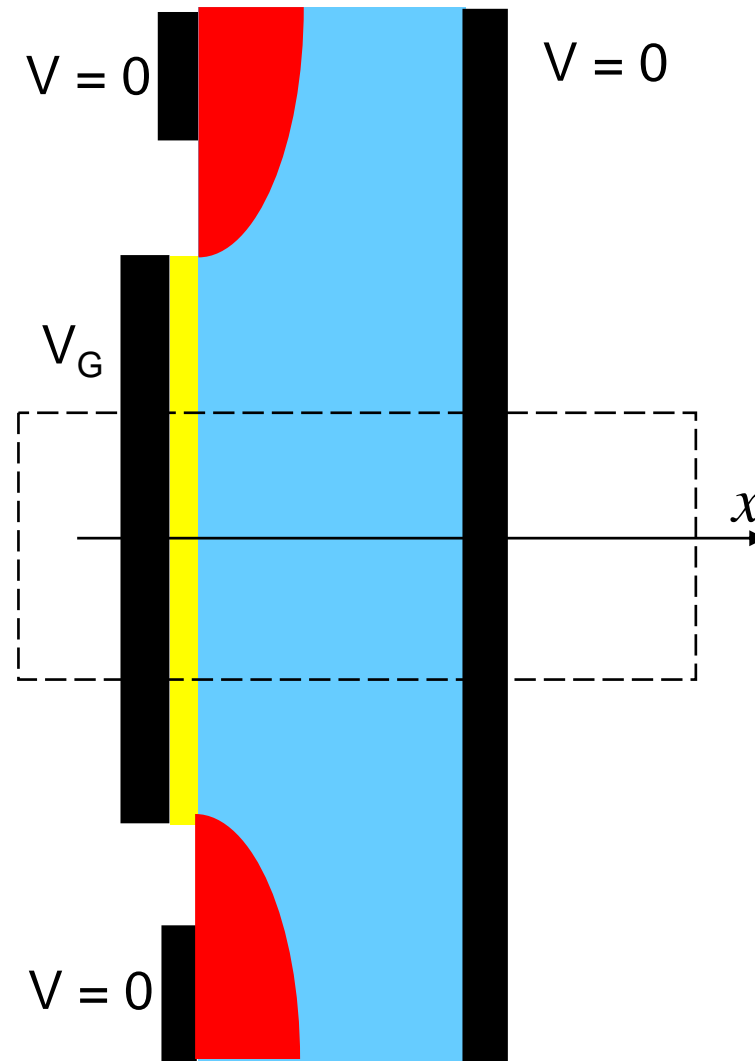
band bending



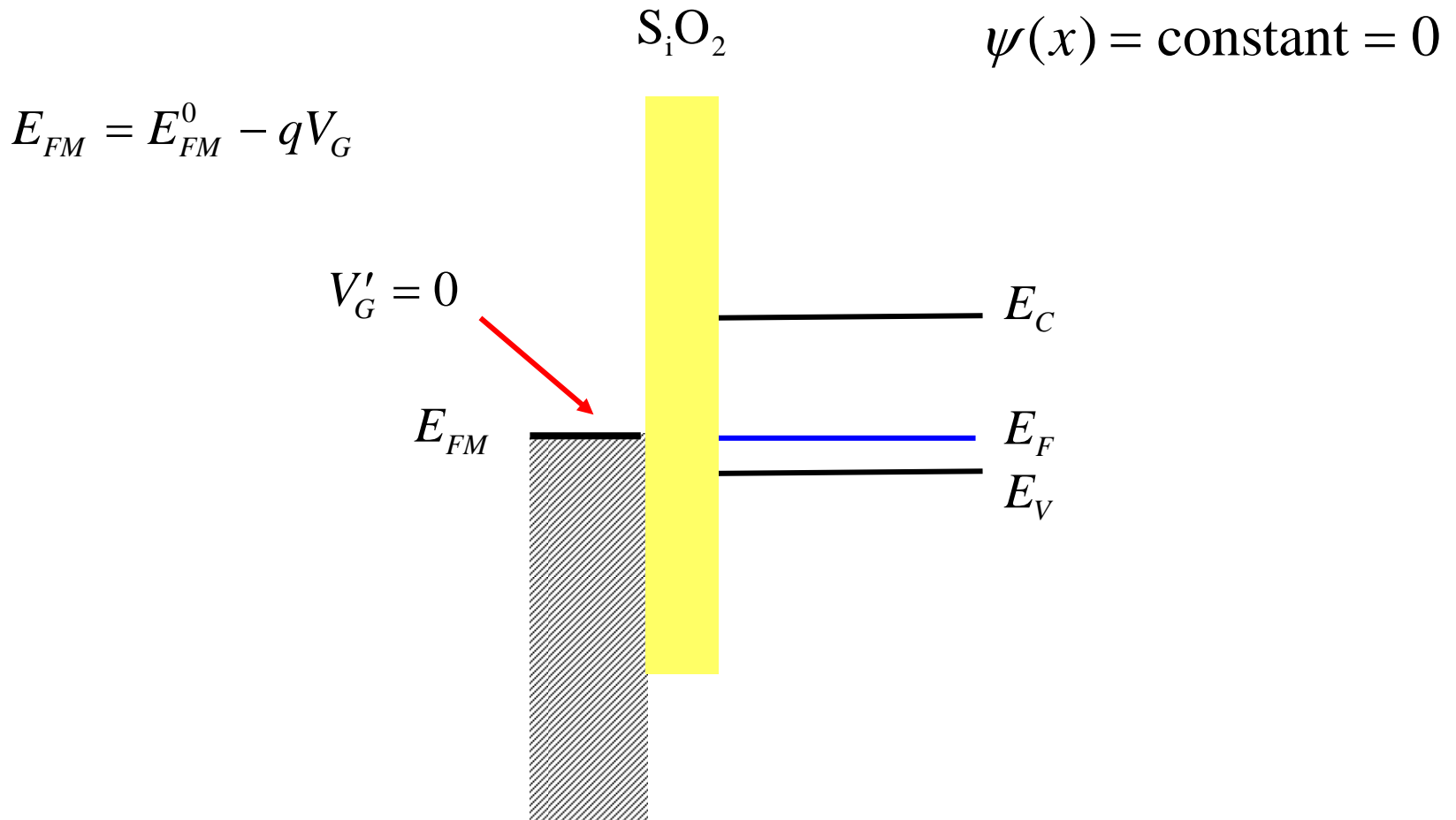
1D MOS electrostatics ($L \gg T_{ox}$)



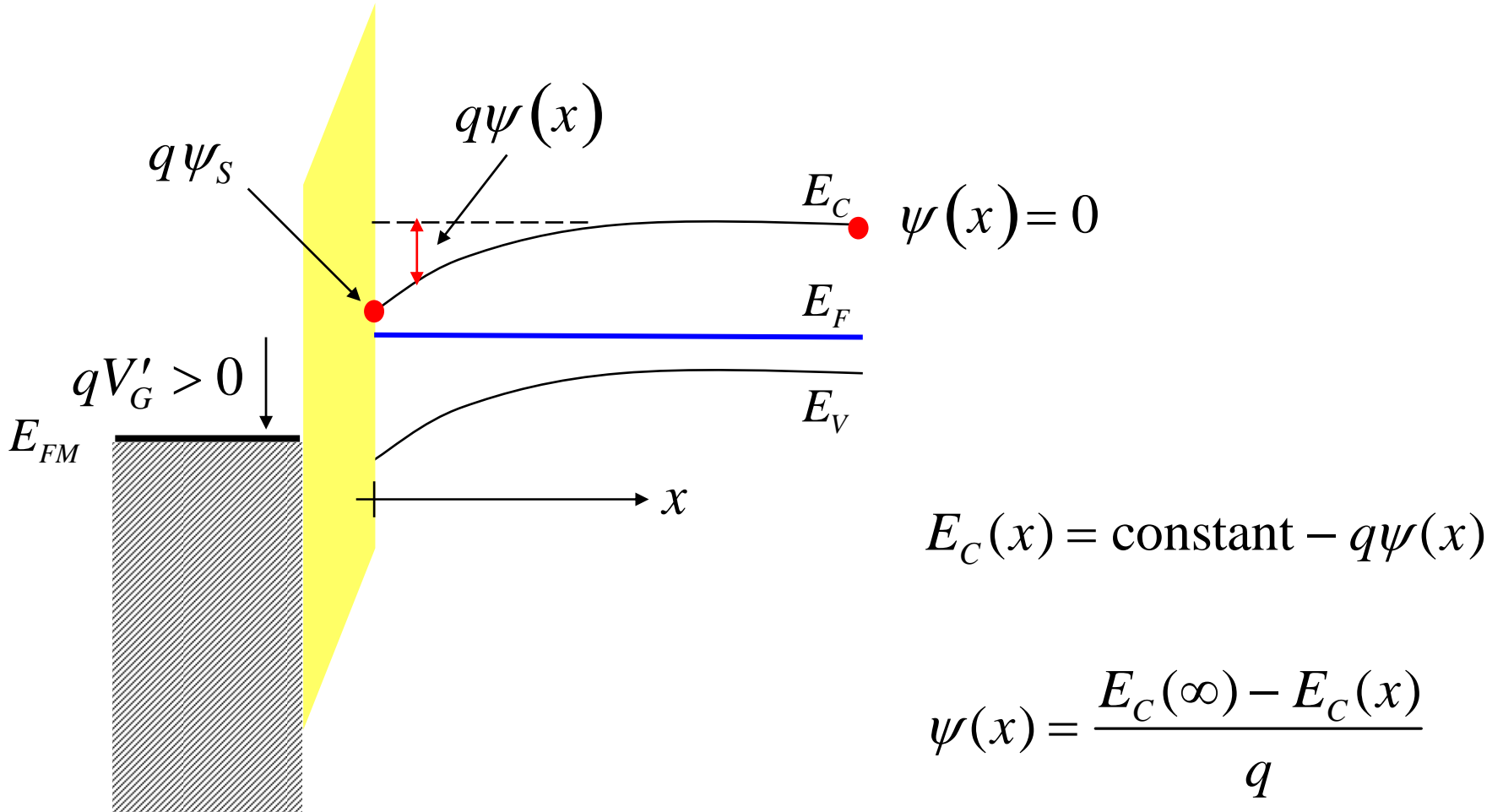
1D MOS electrostatics ($L \gg T_{ox}$)



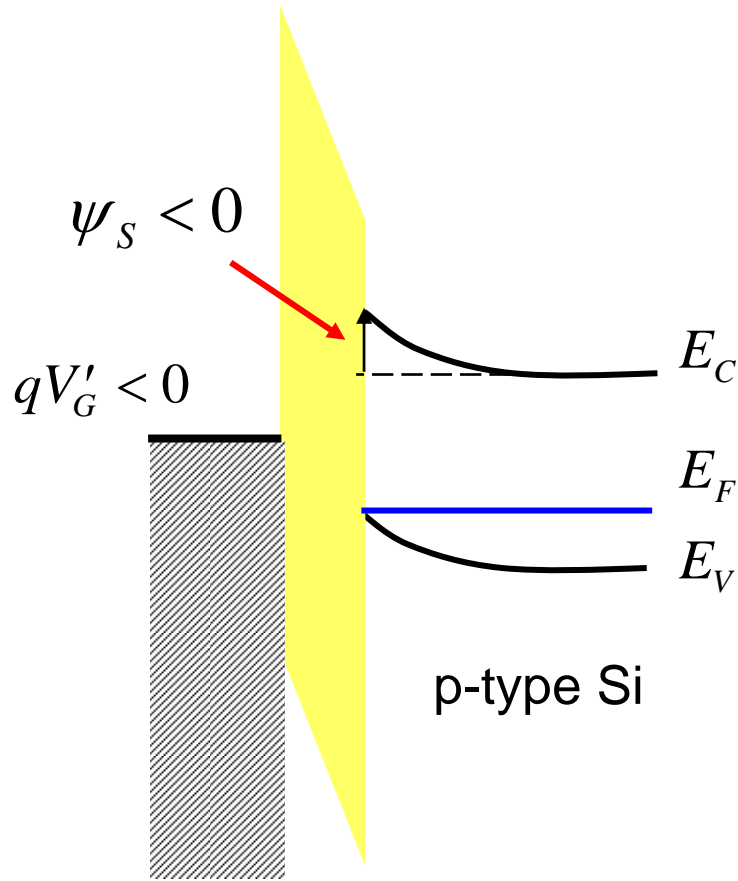
'flat band' conditions



electrostatic potential



accumulation



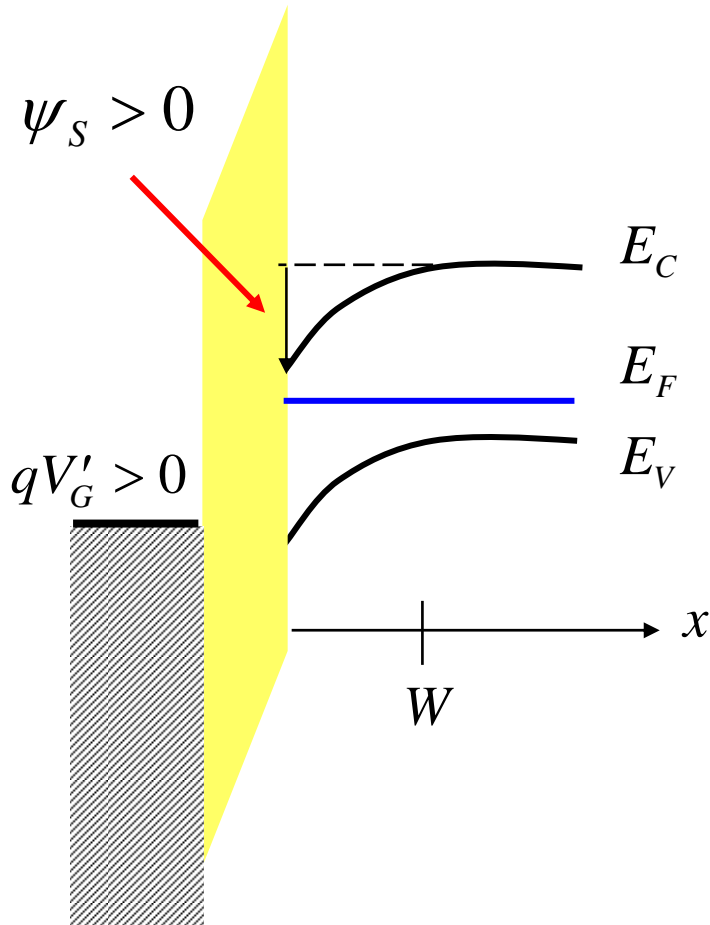
- bands bend up
- surface potential < 0
- hole density increases exponentially

$$p_0(x) = N_V e^{(E_V(x) - E_F)/k_B T}$$

$$Q_S = + \int_0^{\infty} q (p_0(x) - N_A^-) dx \quad \text{C/cm}^2$$

$$|Q_S| \sim e^{-q\psi_s/k_B T} \quad (\text{not quite, but close})$$

depletion



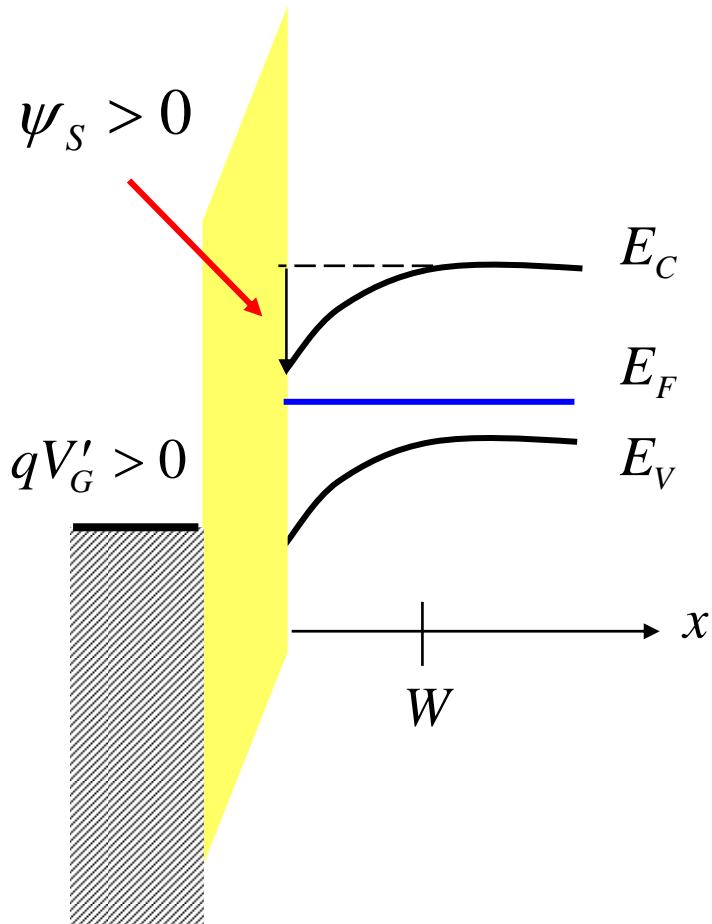
- bands bend down
- surface potential > 0
- For $x < W$:

$$p_0(x) = N_V e^{(E_V(x) - E_F)/k_B T} \approx 0$$

$$n_0(x) = N_C e^{(E_F - E_C(x))/k_B T} \approx 0$$

$$\rho(x) \approx -qN_A \quad (x < W) \quad \text{C/cm}^3$$

depletion (ii)



$$\rho(x) = -qN_A$$

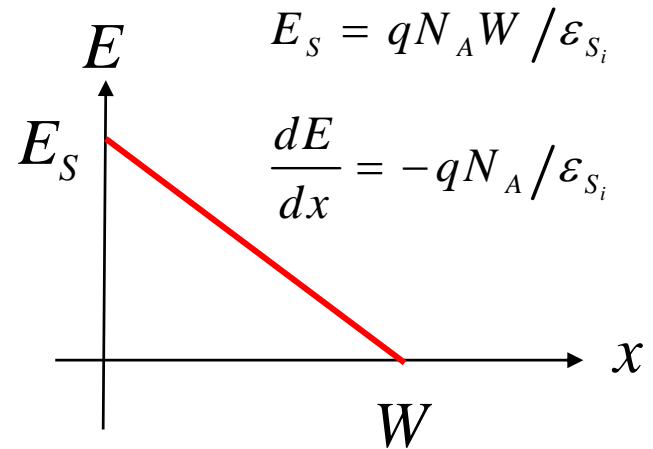
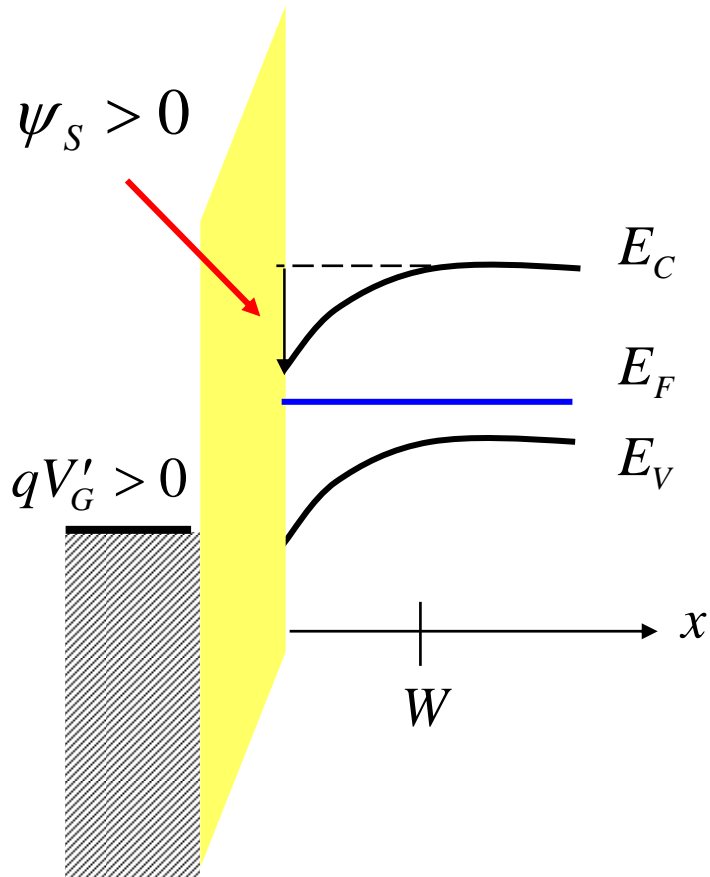
$$\frac{d(\epsilon_{Si}E)}{dx} = \rho(x) = -qN_A$$

$$\frac{dE}{dx} = \frac{-qN_A}{\epsilon_{Si}}$$

$$E(x) = \frac{qN_A}{\epsilon_{Si}}(W - x)$$

$$E_S = \frac{qN_A W}{\epsilon_{Si}} = \frac{-Q_S}{\epsilon_{Si}}$$

depletion (iii)

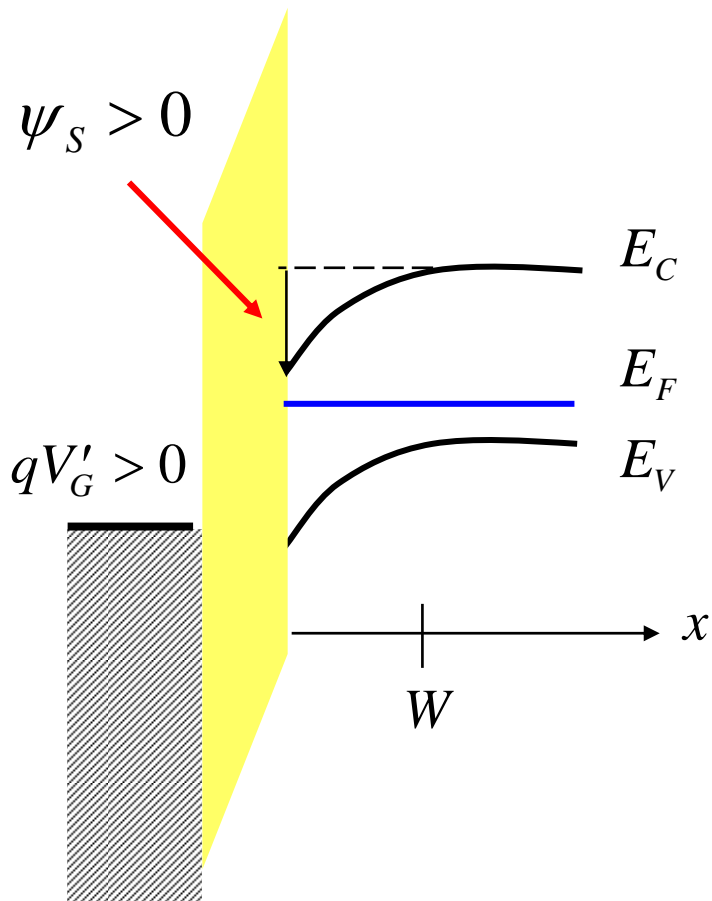


$$\psi(x) = -\int E(x) dx$$

$$\psi_s = \frac{1}{2} E_s W$$

$$W = \sqrt{2\epsilon_{Si}\psi_s / qN_A}$$

depletion (iv)

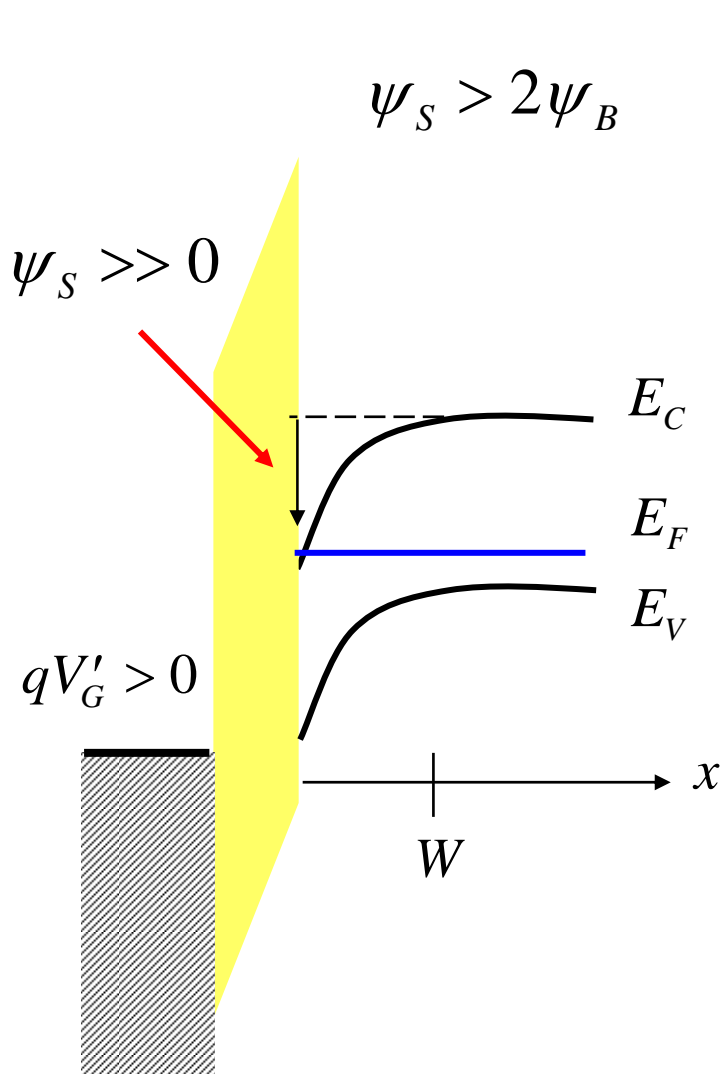


$$W = \sqrt{2\epsilon_{Si}\psi_S/qN_A}$$

$$Q_S = -qN_A W = -\sqrt{2qN_A\epsilon_{Si}\psi_S}$$

$$|Q_S| \sim \sqrt{\psi_S} \quad (\text{very close})$$

inversion



$$\psi_B = \frac{k_B T}{q} \ln \left(\frac{N_A}{n_i} \right)$$

(surface potential to make $n(x=0) = N_A$)

$$p_0(x < W) \approx 0$$

$$n_0(x=0) = N_C e^{(E_F - E_C(x))/k_B T}$$

$$\sim e^{q\psi_S/k_B T}$$

$$Q_S = - \int_0^{\infty} q [n_0(x) + qN_A^-] dx \approx - \int_0^{\infty} qn_0(x) dx$$

$$|Q_S| \sim e^{q\psi_S/k_B T}$$

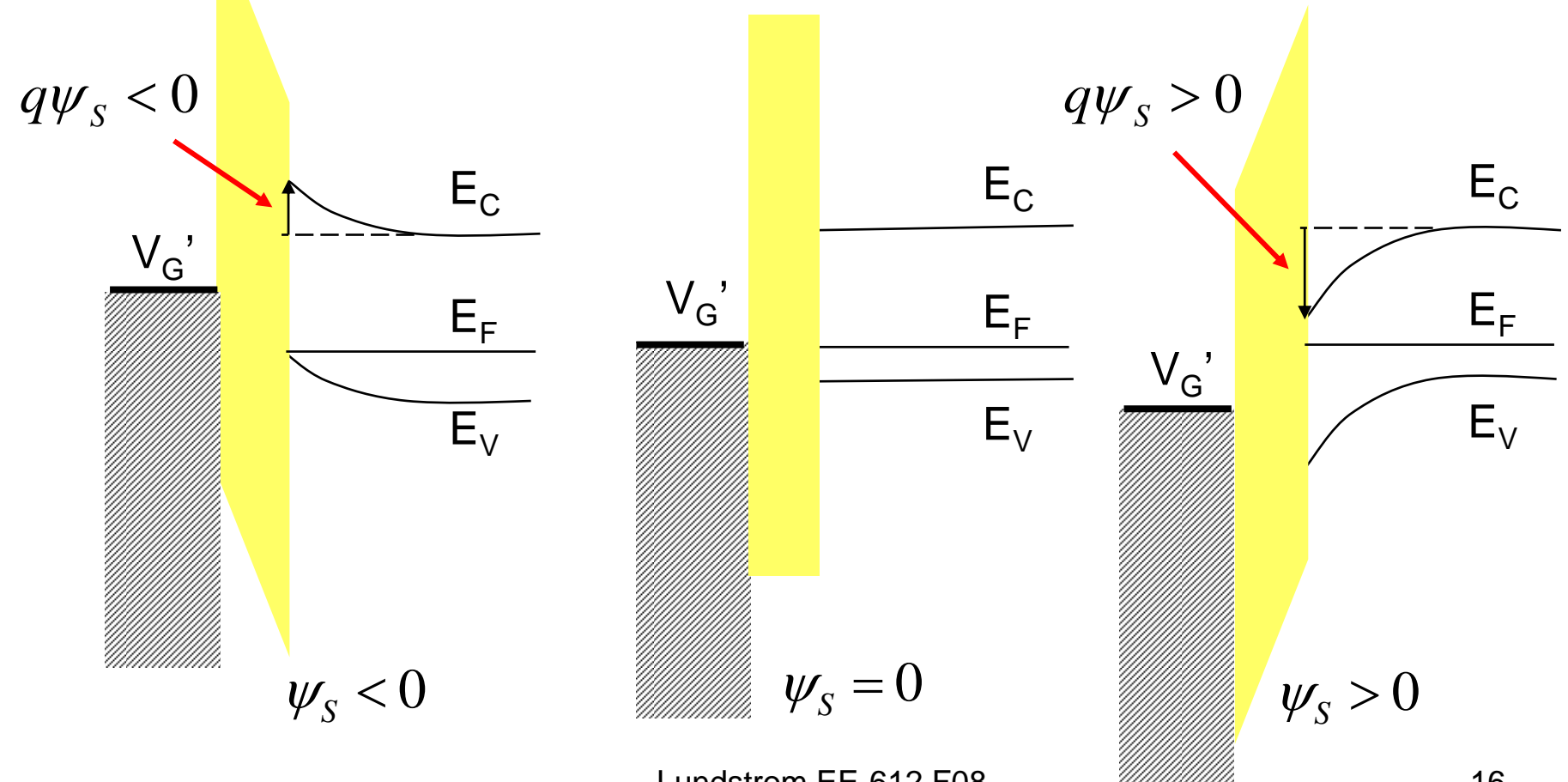
(not quite, but close)

MOS electrostatics

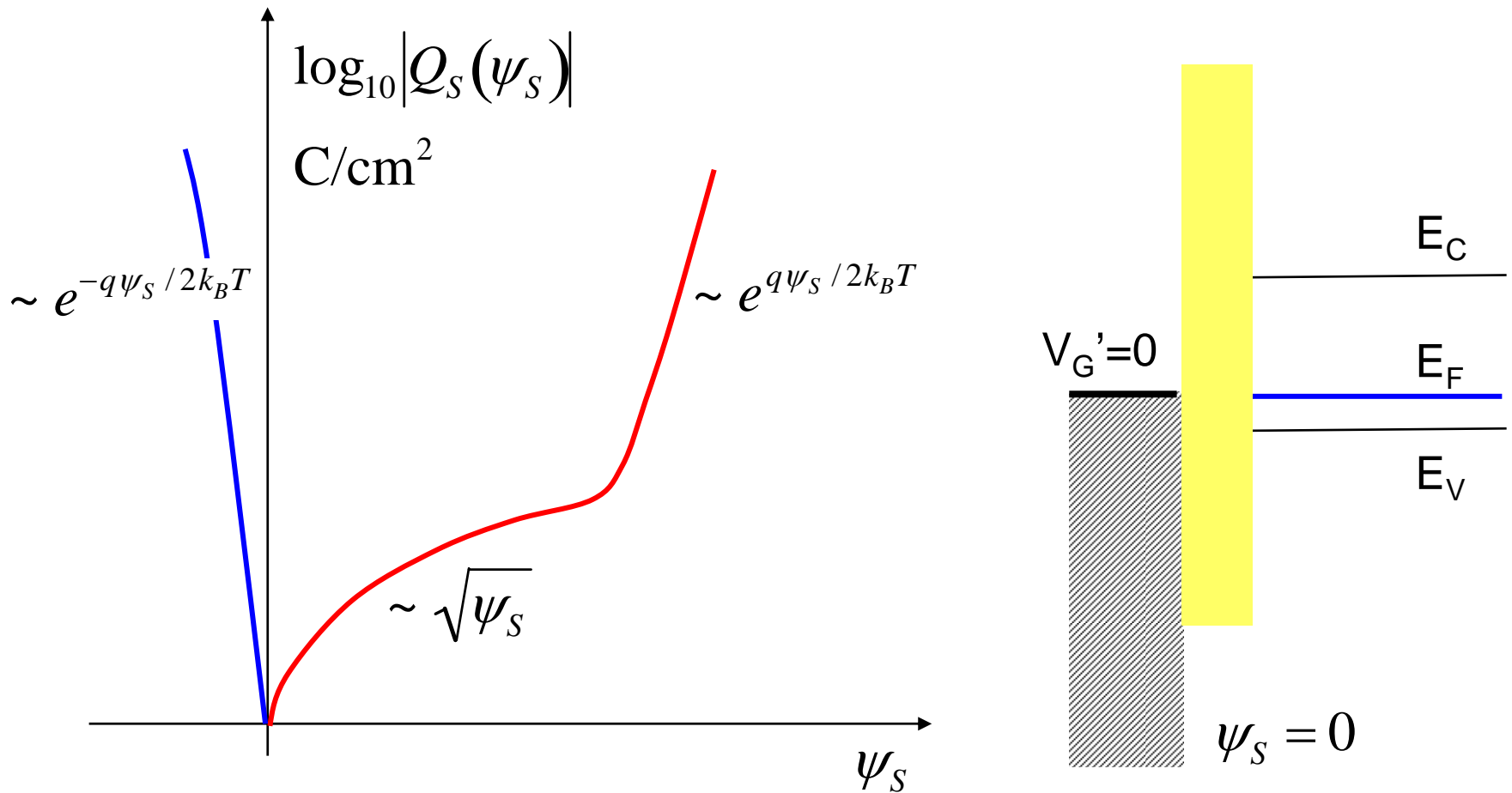
accumulation

flat band

depletion/
inversion



MOS electrostatics



next steps

- 1) Understand how to do the problem 'exactly.'
- 2) Use simpler arguments to understand $Q_S(\psi_S)$.
- 3) Briefly discuss ultra-thin body electrostatics.