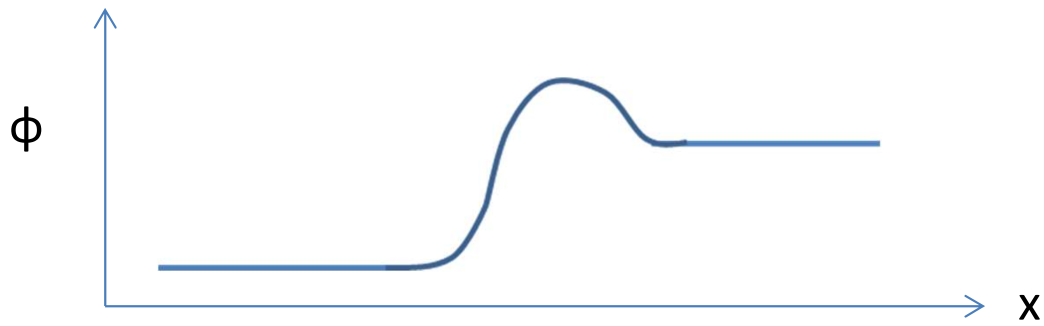
Electrostatics



The potential profile across a device is shown above. The total space charge inside the device is:

(a) Negative

(b) Zero

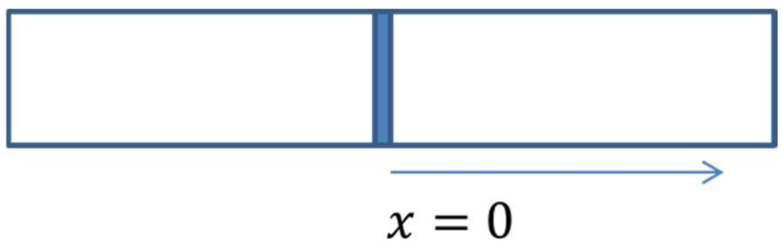
(c) Positive

(d) No idea

$$-\frac{\partial^2 \varphi}{\partial x^2} = \frac{\partial E}{\partial x} = \frac{\rho}{\varepsilon} = q\left(p - n + N_d^+ - N_a^-\right)$$

$$\left[E\right]_L^R = \int_L^R \frac{\rho(x)}{\varepsilon} dx$$

Depletion due to a Sheet Charge



If the *sheet charge density* is -Q, the zero-bias depletion width is given by:

a. There is no depletion

b. $W = \sqrt{\frac{2\varepsilon}{qN_D}\left(\frac{k_B T}{q}\ln\left(\frac{N_D}{n_i}\right)\right)}$

c. $W = \frac{Q}{2qN_D}$

d. $W = \frac{Q}{qN_D}$

What is the barrier-height/well-width?

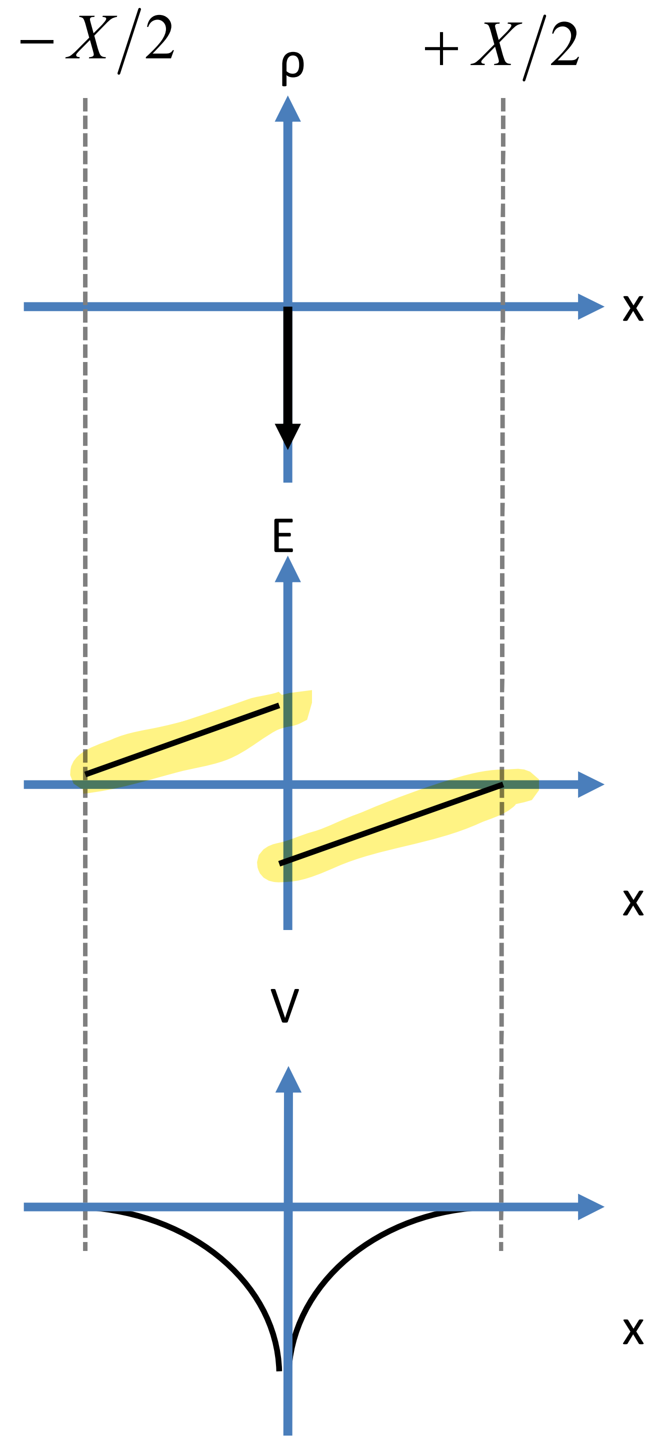
Depletion due to a Sheet Charge

$$Q = qN_D X \Rightarrow X = Q/qN_D$$

$$E_m^{\pm} = \pm qN_D X/2\varepsilon$$

$$\Delta D = \varepsilon \Delta E = 2\varepsilon E_m^{+} = qN_a X = Q$$ Whence?

$$qV_b = \frac{1}{2}E_m^{+} \cdot \frac{X}{2} = \frac{qN_D X^2}{8\varepsilon} = \frac{Q^2}{8\varepsilon qN_D}$$



Reverse Leakage Current – Charge Control Analysis

Consider a *wide* p-n junction. The *approximate* flux of minority electrons that diffuse from the bulk of the p-side to the depletion region per unit time is:

a. $\dfrac{D_n}{\lambda_n}\dfrac{n_i^2}{N_a}$

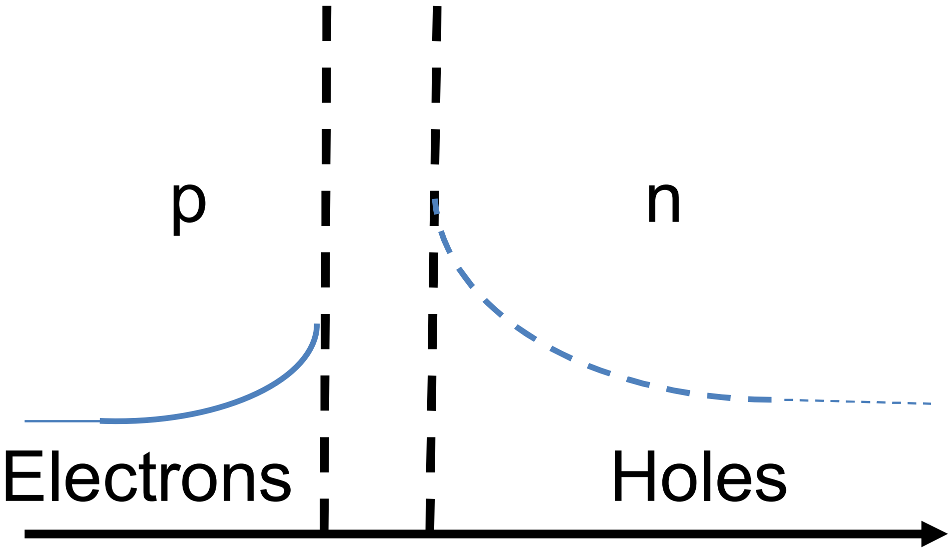
$$J_n(x_P) = \frac{Q_n}{\tau_n} = \frac{q\lambda_n}{\tau_n}\frac{n_i^2}{N_a} = \frac{q\lambda_a^2}{\tau_n\lambda_n}\frac{n_i^2}{N_a} = \frac{qD_n}{\lambda_n}\frac{n_i^2}{N_a}$$

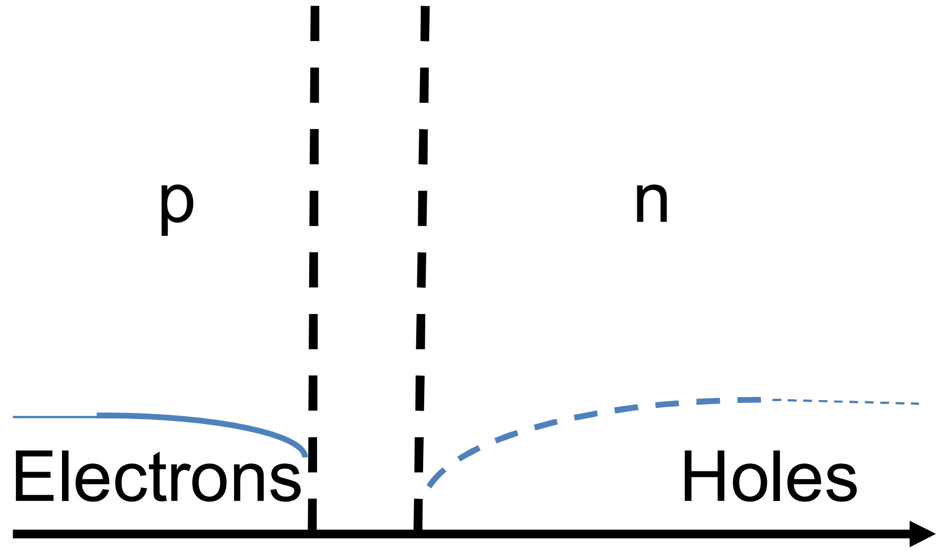
b. $\dfrac{D_n}{W_p}\dfrac{n_i^2}{N_a}$

c. $\dfrac{W_p}{\tau_n}\dfrac{n_i^2}{N_a},\ W_p \gg \lambda_n$

d. None of the above/no idea

Reverse Leakage Current – Charge Control Analysis





$$p_N(x) = p_{N0} + p_{N0}\ (e^{qV_f/k_BT} - 1)e^{-(x-x_N)/\lambda_p}$$

$$\delta p_N(x) = p_{N0}\ (e^{qV_f/k_BT} - 1)e^{-(x-x_N)/\lambda_p}$$

$$J_p(x_N) = \frac{Q_p}{\tau_p} = \frac{q\int_{x_N}^{\infty} \delta p_N dx}{\tau_p} = \frac{q\lambda_p}{\tau_p}\delta p_N(x_N)$$

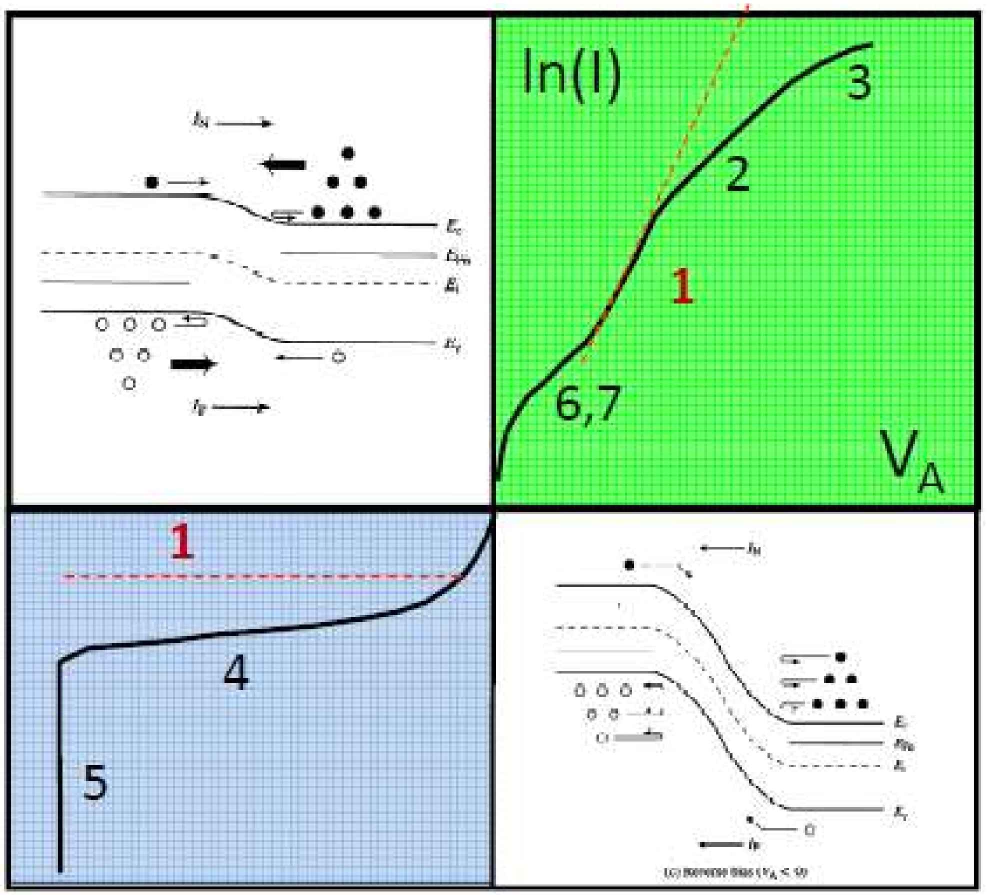
$$J_p(x_N) = \frac{q\lambda_p p_{N0}}{\tau_p}\left(e^{qV_f/k_BT} - 1\right)$$

$$J_n \approx \frac{q\lambda_n}{\tau_n} n_{P0} = \frac{qD_n}{\lambda_n}\frac{n_i^2}{N_a}$$

Ideal vs. Non-ideal Reverse Characteristics

Between Si (E_G = 1.1 eV) and Ge (E_G = 0.7 eV) which one is expected to show characteristic (1) and which one (4)?

$$E_t = E_i \Rightarrow U = \frac{\sigma v_{th} N_t \left(np - n_i^2\right)}{n + p + 2n_i}$$



$$\frac{D_n}{\lambda_n}\frac{n_i^2}{N_a}$$

Diode Reverse Leakage vs. Ohmic

Ohmic

Diode Reverse Leakage

Quasi Fermi Levels in Forward Bias

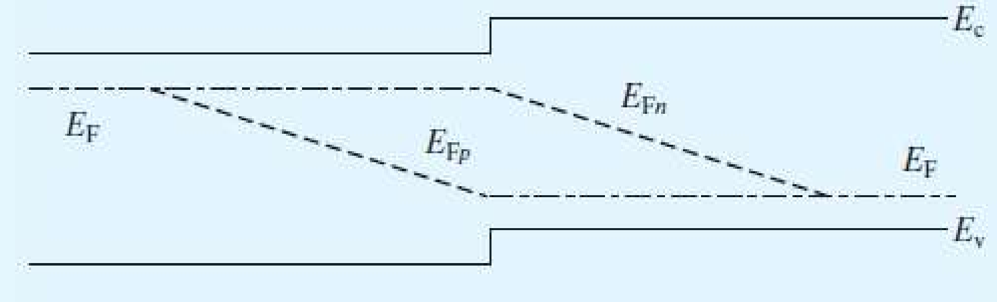


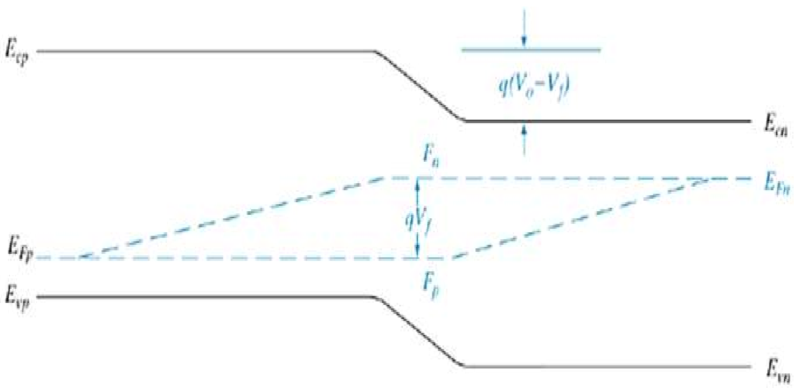
FIGURE 4–19 (b)

$$J_n = n\mu_n \frac{dF_n}{dx} \Rightarrow \frac{dF_n}{dx} = \frac{J_n}{n\mu_n}$$

$$n \propto e^{-x/\lambda_n} \Rightarrow J_n \propto e^{-x/\lambda_n}$$

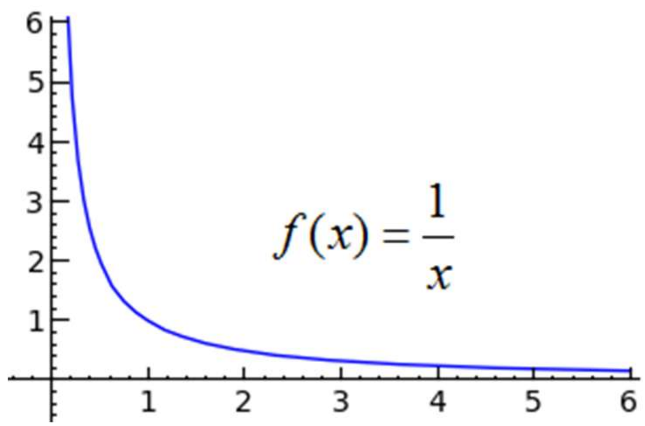
$$\Rightarrow \frac{dF_n}{dx} = \text{constant}$$

Quasi Fermi Levels in Depletion Region

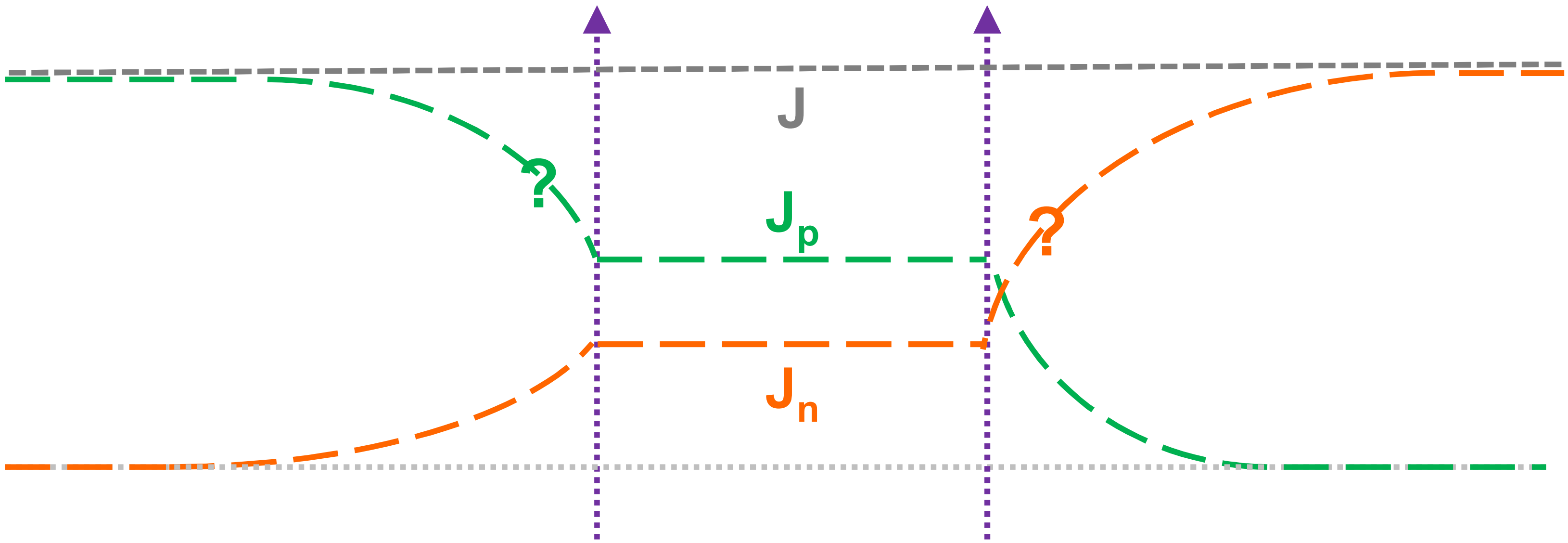


$$J_n = n\mu_n \frac{dF_n}{dx}$$

$$\Rightarrow \frac{dF_n}{dx} = \frac{J_n}{\mu_n n}$$



Current components in Forward Bias

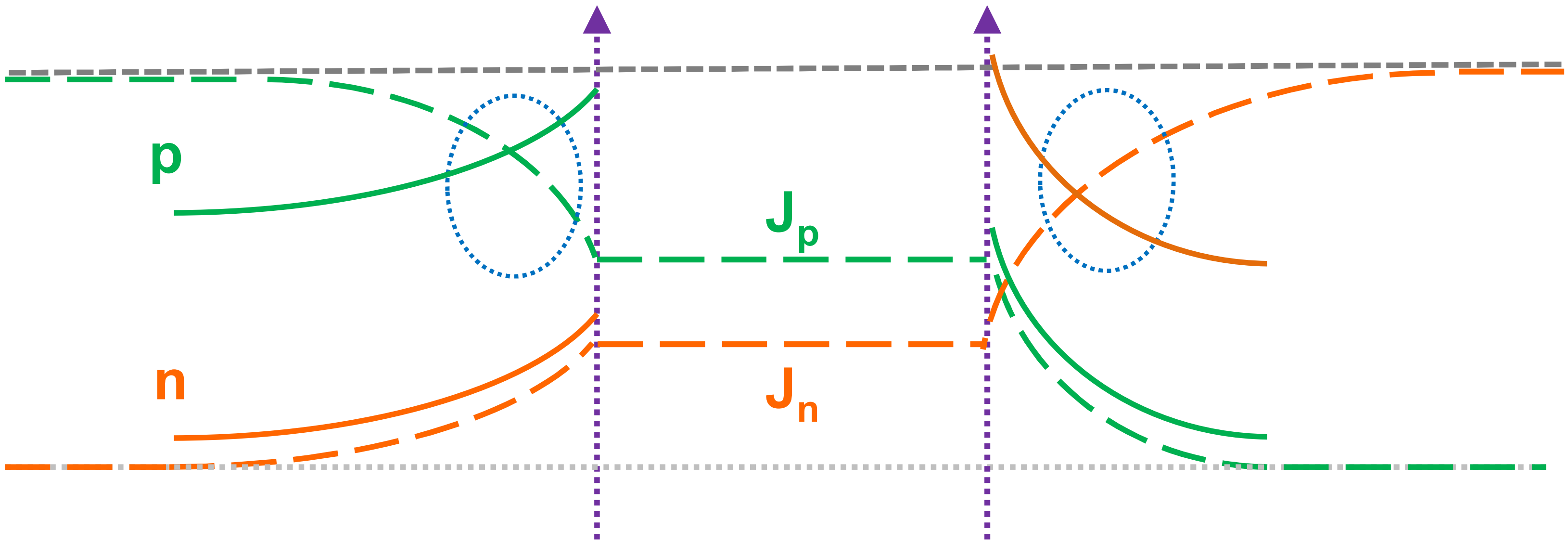


$$\frac{\partial p}{\partial t} = -\frac{1}{e}\vec{\nabla}\cdot\vec{J}_p + \left(G_p - R_p\right)$$

$$\frac{\partial n}{\partial t} = +\frac{1}{e}\vec{\nabla}\cdot\vec{J}_n + \left(G_n - R_n\right)$$

Steady-state: $\vec{\nabla}\cdot\vec{J} = 0$

Current components in Forward Bias



The majority current close to the junction is:

a. Dominated by diffusion

b. Dominated by drift

c. A mix of drift and diffusion

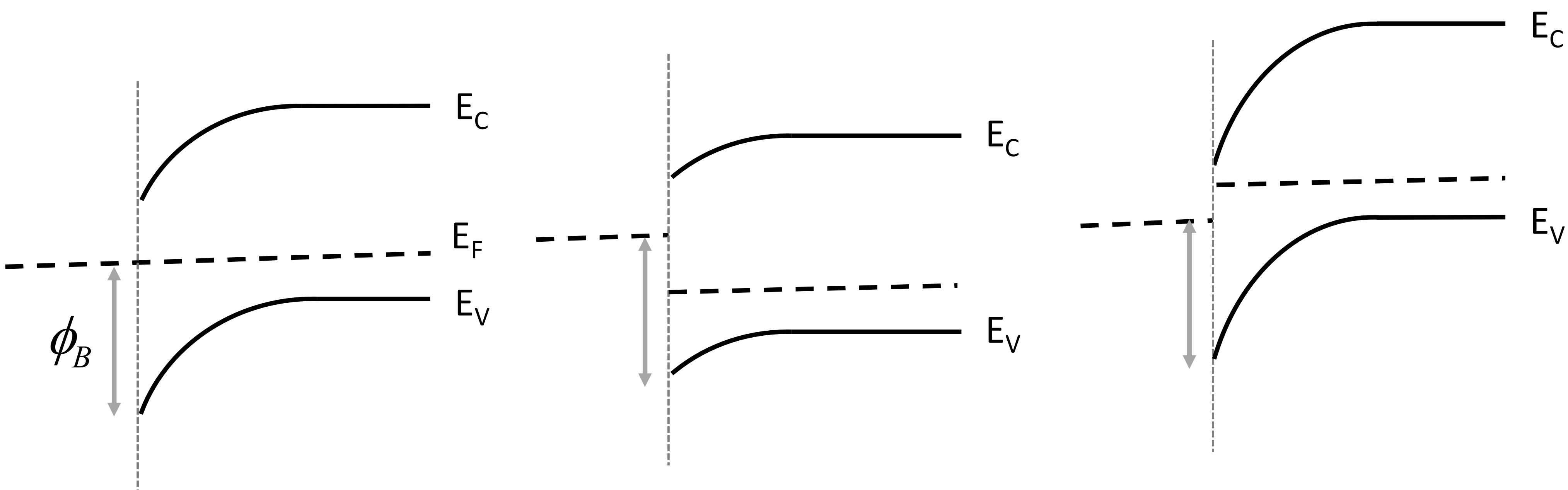
d. This cannot be determined analytically

Ideal Schottky Junction

Consider an *ideal* metal-semiconductor junction.

$$\varphi_s = 4.8eV \quad E_g = 1eV \quad \chi_s = 4eV \quad \varphi_m = 4.3eV$$

Draw the band diagrams: in equilibrium, small $\pm$ bias.

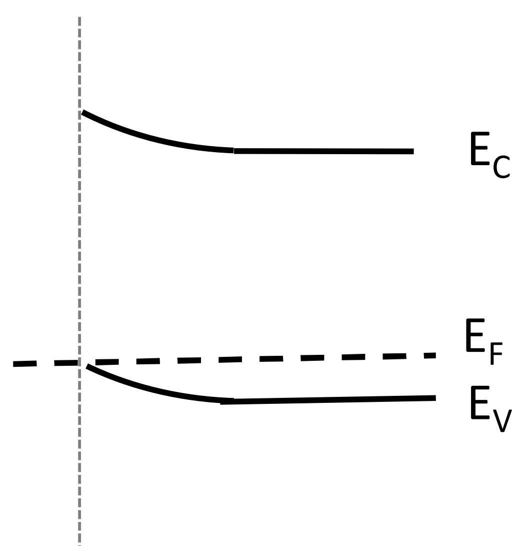


Non-ideal Schottky Junction – Fermi Level Pinning

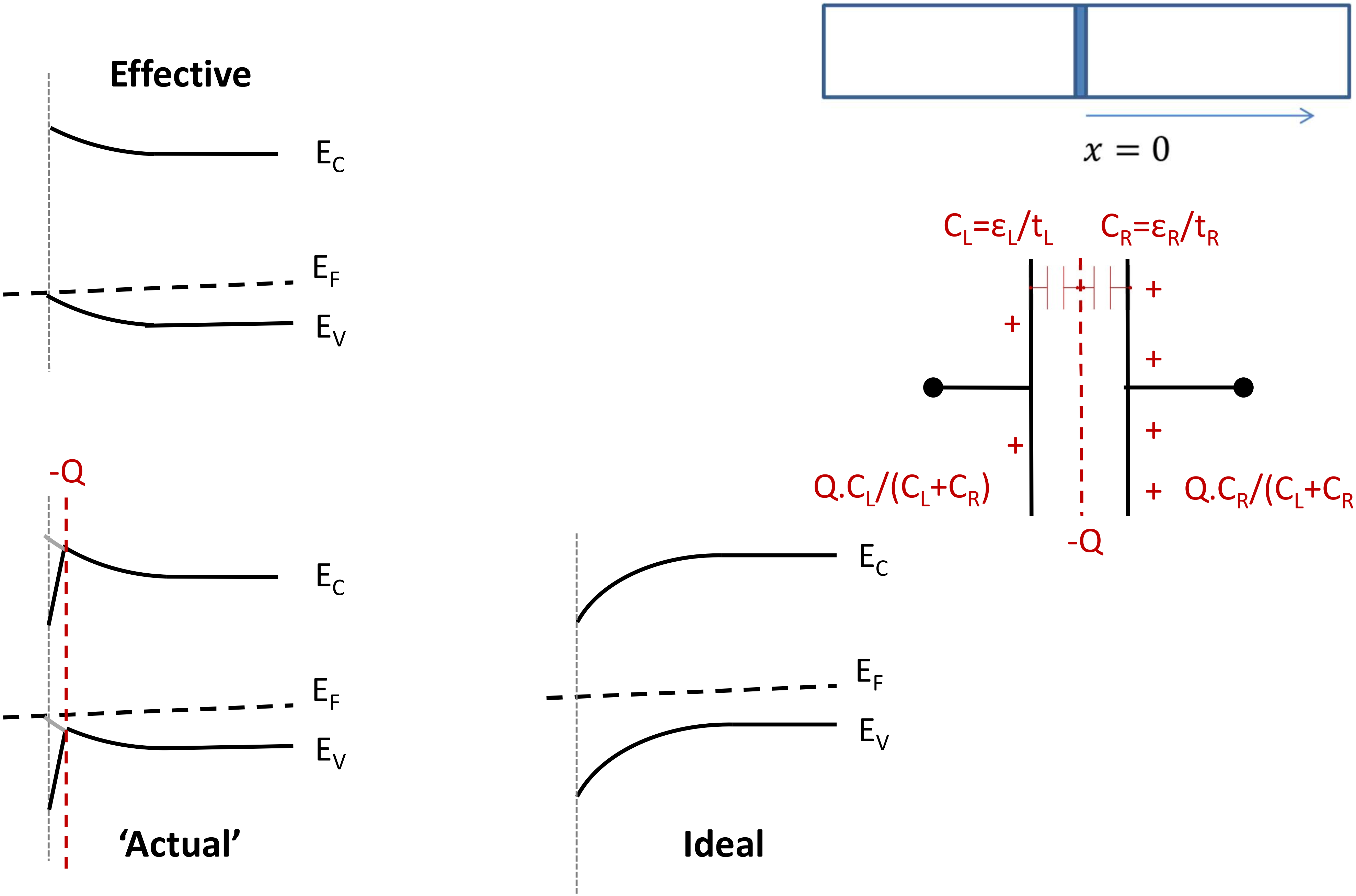
Consider M-S junction, with *Fermi-level pinning* (no modulation of potential with workfunction) at VB.

$$\varphi_s = 4.8eV \quad E_g = 1eV \quad \chi_s = 4eV \quad \varphi_m = 4.3eV$$

Draw the band diagram in equilibrium. How is the band-bending related to the initial difference in Fermi levels?



Non-ideal Schottky Junction – Fermi Level Pinning



V_{BR} vs. doping