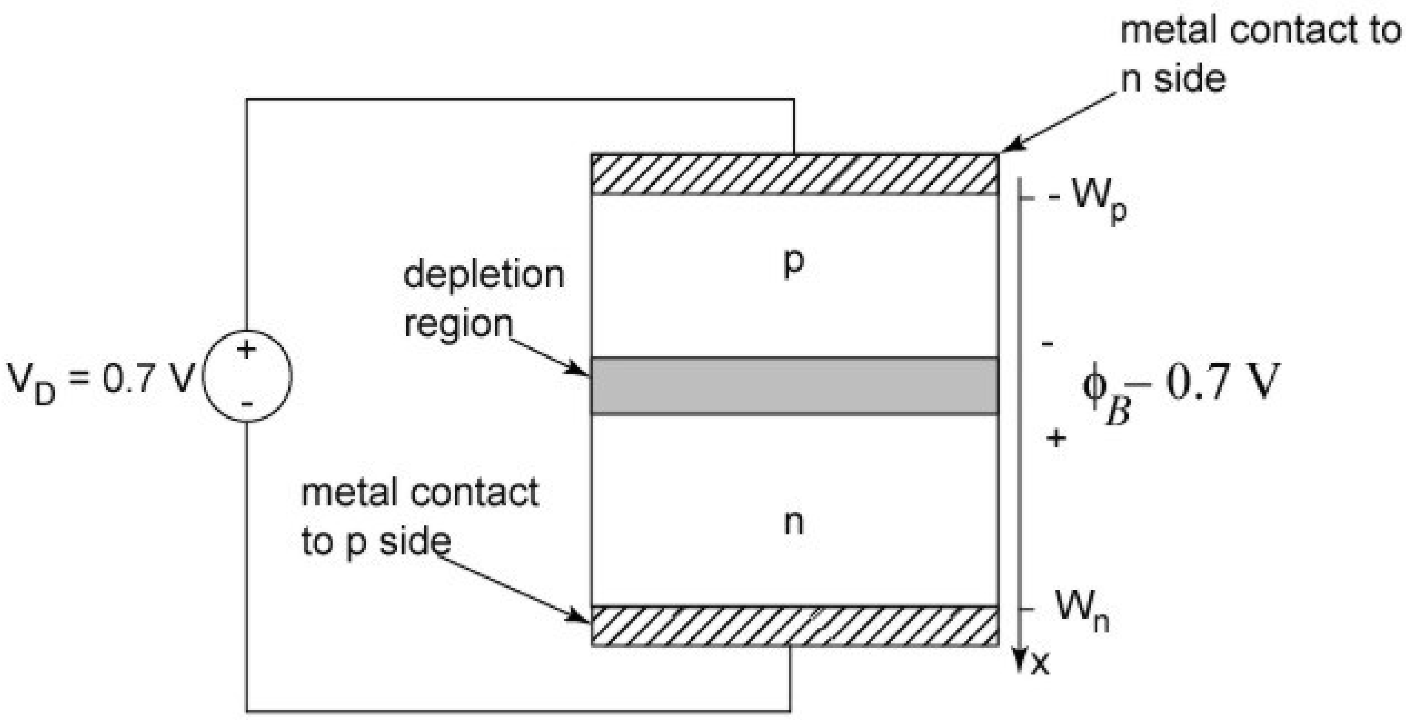
Lecture 17

- Last time:
  - Complete small-signal model: add capacitors
  - P-channel MOSFET
- Today :
  - pn junctions under *forward* bias (Chapter 6)

Junction Diode with $V_D = 0.7$ V



Barrier is reduced by forward bias
(what about "ohmic contacts"?)

What Happens Inside the Junction?

Electric field in the depletion region is reduced → imbalance and net transport of holes from p side into n side and electrons in the other direction

Physical process is called *diffusion* and results in a diffusion current density

$$J_p^{diff} = -qD_p \frac{dp}{dx} \qquad J_n^{diff} = qD_n \frac{dn}{dx}$$

note "downhill" = - $d(\ )/dx$

Minority Carriers at Junction Edges

Minority carrier concentration at boundaries of depletion region increase as barrier lowers … the function is

$$\frac{p_n(x = x_n)}{p_p(x = -x_p)} = \frac{\text{(minority) hole conc. on n-side of barrier}}{\text{(majority) hole conc. on p-side of barrier}}$$

$$= e^{-(Barrier\ Energy)/kT}$$

$$\boxed{\frac{p_n(x = x_n)}{N_A} = e^{-q(\phi_B - V_D)/kT}}$$

(Boltzmann's Law)

The Thermal Voltage

Define $V_{th} = q\ /\ kT$ as the *thermal voltage*

Value: $q = 1.6 \times 10^{-19}$ C, $k = 1.38 \times 10^{-23}$ J/K
$T = 300$ K

$V_{th} = 26$ mV at room temperature

"Law of the Junction"

Minority carrier concentrations at the edges of the depletion region are given by:

$$p_n(x = x_n) = N_A e^{-q(\phi_B - V_D)/kT}$$

$$n_p(x = -x_p) = N_D e^{-q(\phi_B - V_D)/kT}$$

Note 1: N_A and N_D are the majority carrier concentrations on the *other* side of the junction

Note 2: we can reduce these equations further by substituting $V_D = 0$ V (thermal equilibrium)

Note 3: assumption that $p_n << N_D$ and $n_p << N_A$

Thermal Equilibrium Case

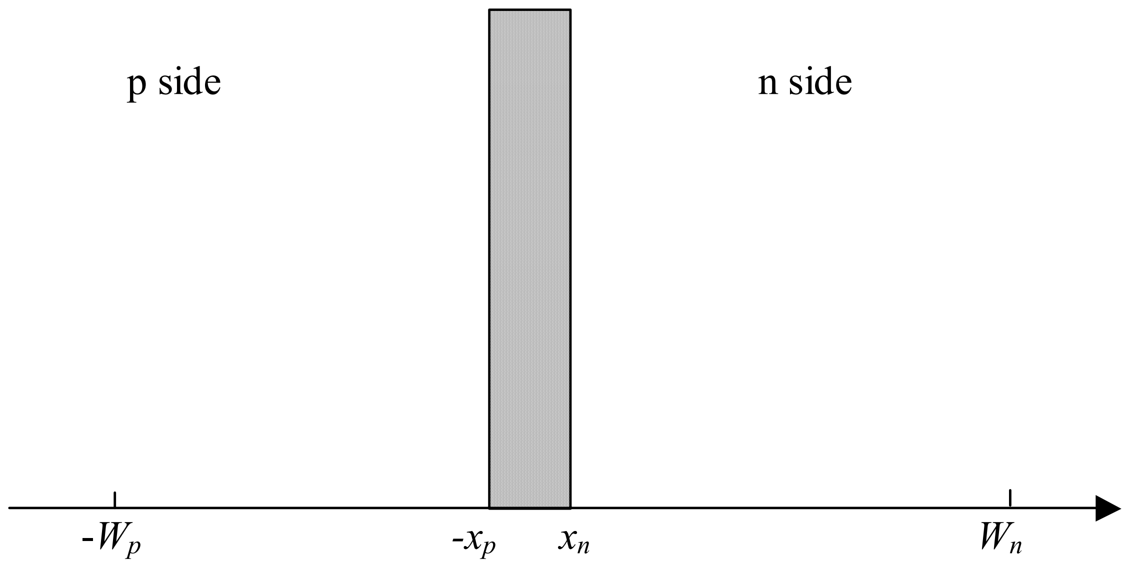
Define p_{no} as thermal equilibrium hole concentration on the n-side of the junction …

$$p_{no} = \frac{n_i^2}{N_D} = N_A e^{-(\phi_B - 0)/V_{th}}$$

Solve for the built-in barrier

Alternative form of junction law:

Boundary Conditions

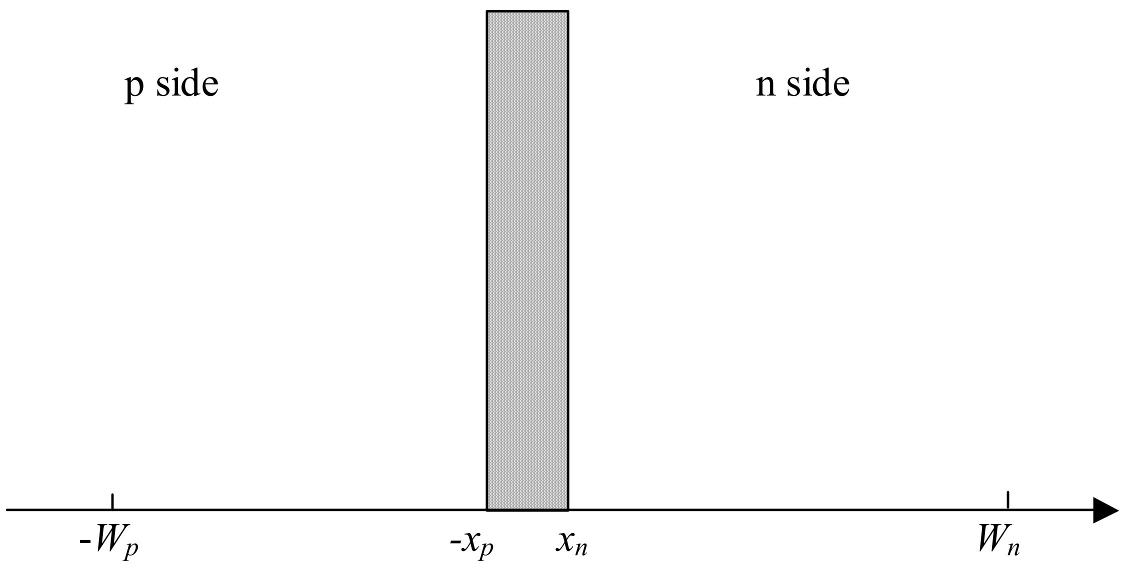


Depletion region edges:

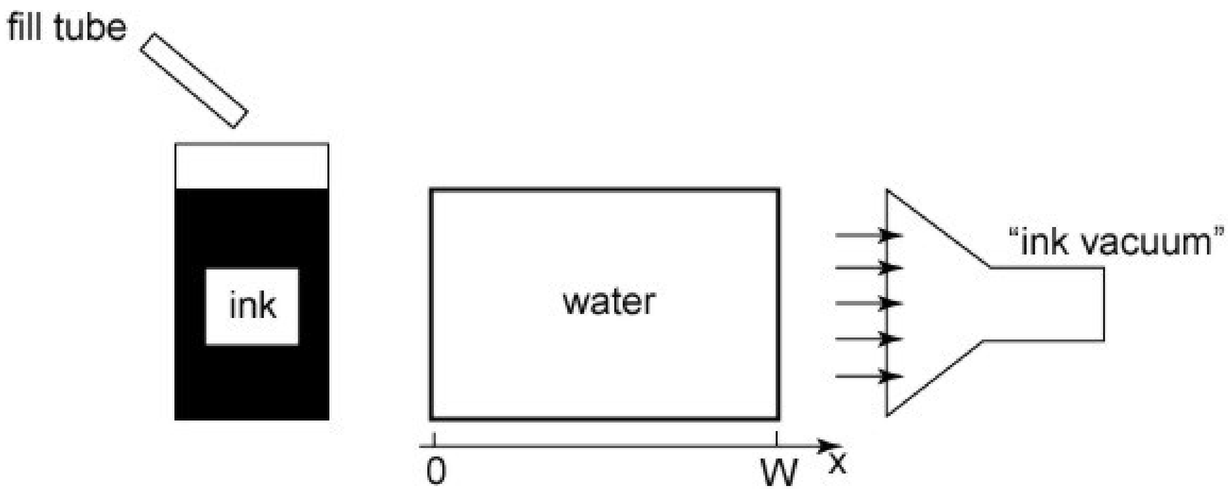
Ohmic contacts:

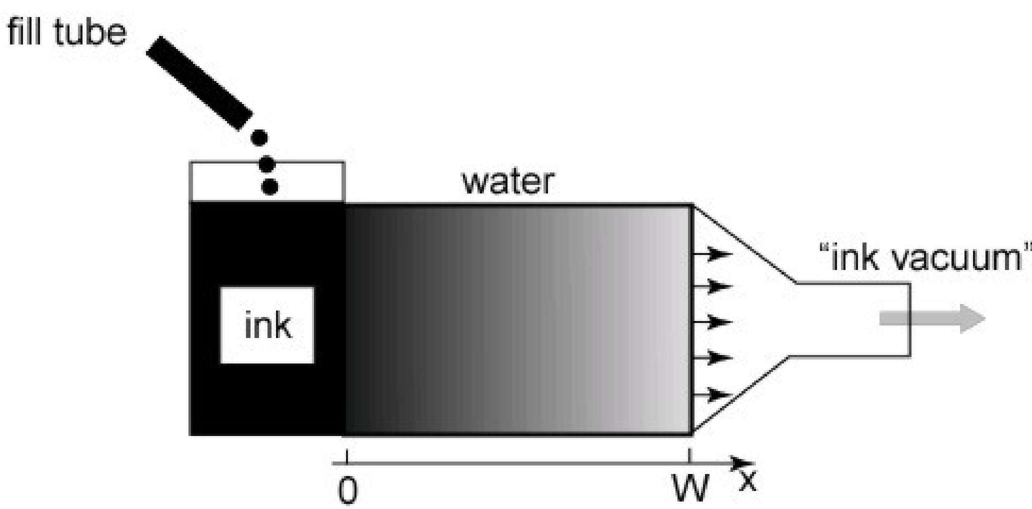
Steady-State Concentrations

Assume that none of the diffusing holes and electrons recombine → get straight lines …



Diffusion Analogy





Diode Current Densities

$$J_n^{diff} = qD_n \left. \frac{dn_p}{dx} \right|_{x=-x_p}$$

$$J_p^{diff} = -qD_p \left. \frac{dp_n}{dx} \right|_{x=x_n}$$

Total current:

$$J =$$