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 $\rightarrow$ 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

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

note “downhill” = $- d()/dx$

Minority Carriers at Junction Edges

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

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

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

$$\frac{p_n(x = x_n)}{N_A} = e^{-q(\phi_B - V_D)/kT} \quad \text{(Boltzmann’s Law)}$$
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:

\[
\begin{align*}
  p_n (x = x_n) &= N_A e^{-q(\phi_B - V_D)/kT} \\
  n_p (x = -x_p) &= N_D e^{-q(\phi_B - V_D)/kT}
\end{align*}
\]

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 \( p_n \ll N_D \) and \( n_p \ll N_A \).
Thermal Equilibrium Case

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

$$p_{no} = \frac{n_i^2}{N_D} = N_A e^{-\frac{(\Phi_B - \Phi_0)}{V_{th}}}$$

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 \(\rightarrow\) get straight lines …
Diode Current Densities

\[ J_{n}^{\text{diff}} = qD_{n} \frac{dn_{p}}{dx} \bigg|_{x=-x_{p}} \]

\[ J_{p}^{\text{diff}} = -qD_{p} \frac{dp_{n}}{dx} \bigg|_{x=x_{n}} \]

Total current:

\[ J = \]