MOSFET SPICE Model

Many "levels" ... we will use the square-law "Level 1" model
See H&S 4.6 + Spice refs. on reserve for details.

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.Model MODN NMOS LEVEL = 1 VTO = 1 KP = 501 LAMBDA = .033 GAMMA = .6
+ PHI = 0.8 TOX = 1.5E-10 CGDO = 5E-10 CGSO = 5E-10 CJ = 1E-4 CJSW = 5E-10
+ MJ = 0.5 PB = 0.95
.
.Model MODP PMOS LEVEL = 1 VTO = -1 KP = 25U LAMBDA = .033 GAMMA = .6
+ PHI = 0.8 TOX = 1.5E-10 CGDO = 5E-10 CGSO = 5E-10 CJ = 3E-4 CJSW = 3.5E-10
+ MJ = 0.5 PB = 0.95
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Lecture 17

- Last time:
  - Complete small-signal model: add capacitors
  - P-channel MOSFET

- Today:  
  - pn junctions under forward bias (Chapter 6)

\[ V_D = 0.7 \text{ V} \]

Junction Diode with \( V_D = 0.7 \text{ V} \)

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

\[
\begin{align*}
J_p^{\text{diff}} &= -qD_p \frac{dp}{dx} \\
J_n^{\text{diff}} &= qD_n \frac{dn}{dx}
\end{align*}
\]

note "downhill" = - \(d(\ )/dx\)
Minority Carriers at Junction Edges

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

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

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

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

(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 $p_n \ll N_D$ and $n_p \ll N_A$
**Thermal Equilibrium Case**

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

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

Solve for the built-in barrier

$$P_n = P_{no} \cdot e^{V_D / V_{th}}$$

Alternative form of junction law:

**Boundary Conditions**

Depletion region edges:  
$$P_n = P_{no} \cdot e^{V_D / V_{th}}$$

Ohmic contacts:  
$$P_n = P_{no}$$
Steady-State Concentrations

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

Diffusion Analogy
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:

\[ J = -qD_p \left[ \frac{P_n(W_p) - P_n(x)}{w_n - x_n} \right] + qD_n \left[ \frac{P_p(x_n) - P_p(-x_p)}{w_p - x_p} \right] \]