HW Due thurs night
OH Lydin W 4-5 295 Cory, me W3-4, Th 4:30-5:30
scanned lectures

Review diode physics

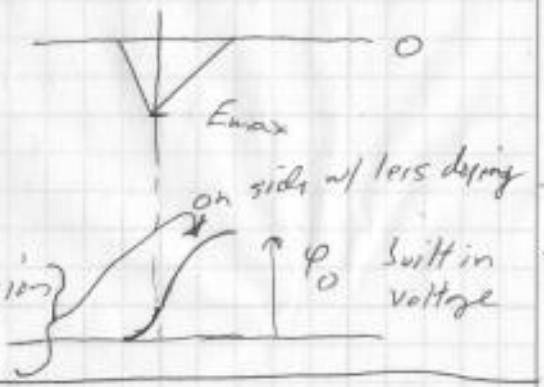
BJTs

Diodes

Abrupt junction (rare)

depletion region

Gauss: $\oint E \cdot dA = \frac{Q}{\epsilon}$



$V = -\int E \cdot dl$

2 gradients
most of depletion region
most of voltage

Breakdown $E_{BD} \sim 3 \times 10^7 \frac{V}{m} = 30 \frac{V}{\mu m}$

with no contact, no net current

Are there currents? Yes

Drift = diffusion

minority carriers near edge of depletion region

important in reverse bias

barrier height (φ_0)

distribution of carrier energy $\sim e^{-E/k_BT}$

dominates in forward bias

Einstein relation: $\frac{D}{\mu} = k_B T$

$\Rightarrow \varphi_0 = V_{TH} \ln \frac{N_A N_D}{n_i^2}$

$V_{TH} = \frac{k_B T}{q} = 25$ mV @ R.T.

n_i = intrinsic carrier concentration

$\cong 10^{10} \frac{ehp}{cc}$ @ R.T.

$\boxed{np = n_i^2}$

varies by 10^5 from -40 to +85 C

write N_A, N_D as multiples of n_i, R.T.

$N_A = 10^x n_{i,RT}$

$N_D = 10^y n_{i,RT}$

10^{14} to $10^{20} \frac{at}{cc}$

100 Ωcm to 1 mΩcm

140/240A 20 SP W2L1

then $\frac{N_A N_D}{n_i^2} = 10^x 10^y = 10^{x+y}$ $\quad x, y \in [4, 10]$

$\varphi_0 = V_{TH} \ln 10^{x+y} = \underbrace{V_{TH} \ln(10)}_{60\text{ mV @ R.T}} (x+y)$

$\Rightarrow$ $\boxed{\text{memorize!}}$ $\Leftarrow$

if $N_n = 10^{15}$, $N_p = 10^{20}$

what is φ_0? (in n, p)

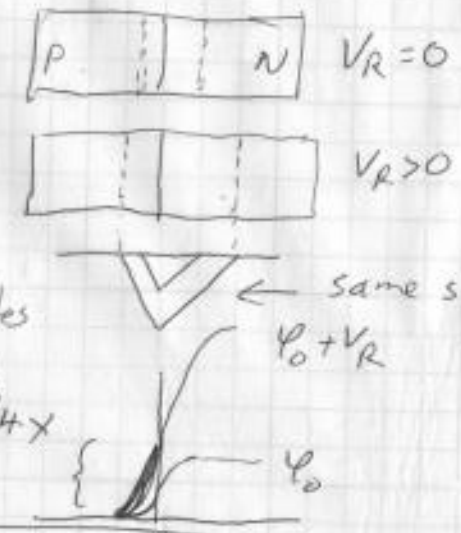
relative width of depletion region?

relative voltage drop in n, p?

minority carrier conc @ R.T?

Reverse bias

$V_R = -V_D$



say depl. region doubles

Peak field doubles

integral on each side increases 4x

$(\varphi_0 + V_R)^{1/2}$ linearly related to $\left(\begin{array}{l}\text{charge} \\ \text{field} \\ \text{depl region width}\end{array}\right)^2$

$\begin{array}{l}\text{charge} \\ \text{field} \\ \text{width}\end{array} \sim \sqrt{\varphi_0 + V_R} = \sqrt{\varphi_0 - V_D}$ $\quad V_D < 0$

EX: $W_D = 1\mu m$ when $V_D = -3$, $\varphi_0 = 1V$

what is W_D when $V_D = -15$?

A: $2\mu m$

what bias would give $10\mu m$? A: $-400V$

will diode support that? A: no. $\frac{40V}{\mu m} > E_{BD}$

In reverse bias, will the current (per unit area) be greater for heavily doped junctions, or lightly doped junctions?

what if I shine light on the junction?

what if I forward bias the junction?

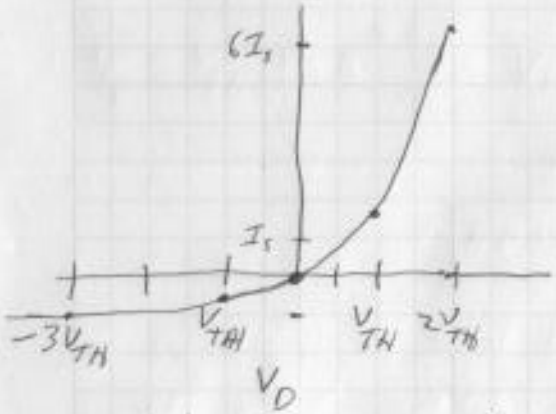
Reduces barrier height. e^{E/k_BT}

Every 25 mV @ R.T. increases diffusion current by $e^1 = 2.7$

Every $(25mV)\ln(10) = 60mV$ increases diffusion current by 10

$I_D = I_s\left(e^{V_D/V_{TH}} - 1\right)$

the -1 is only important if $-3V_{TH} < V_D < 3V_{TH}$

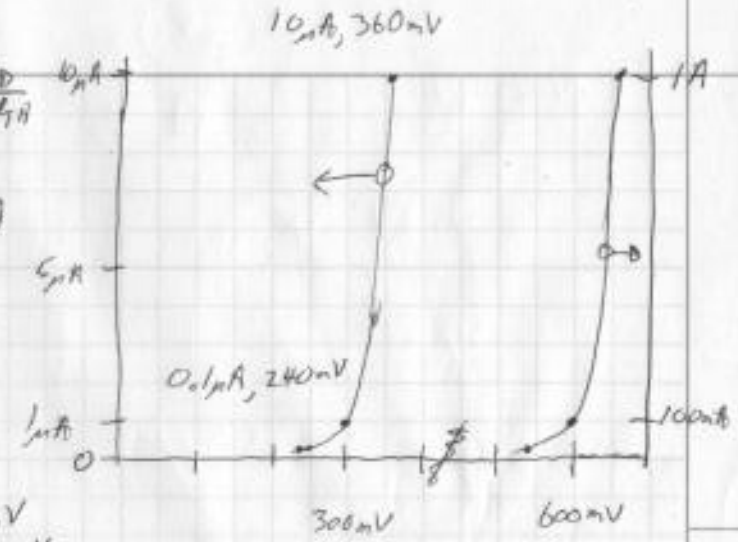


$I_s(e^{-1}-1)$ $\quad$ $I_s(e-1) = 1.7 I_s$

$I_s(e^{-3}-1)$ $\quad$ $I_s(e^{2}-1) = 6.4 I_s$

$I_D = I_s e^{\frac{V_D}{V_{TH}}}$

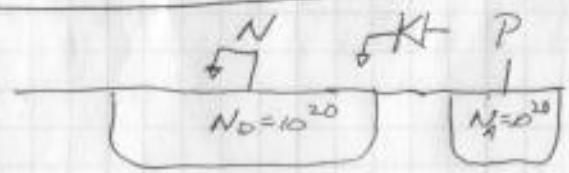
Ex: $I_s = 10^{-11}$ A



when $V_D = 300$mV

$I_D = 10^{-11} e^{\frac{300\text{mV}}{k_B T/q}}$

$= 10^{-11} A\, e^{\frac{(60\text{mV})5}{V_{TH}}} = (10^{-11} A)\, 10^5 = 1\mu A$



$N_A = 10^{15}$

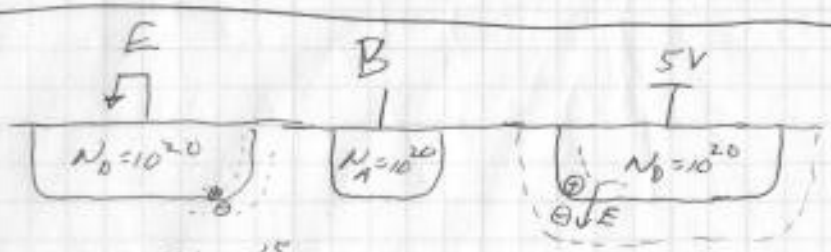
Depletion region primarily in? P region

Leakage current from? h^+ drift

Forward bias current primarily? e^- diffusion, $10^5:1$

what happens to e^- in p region?

recombination. Lifetime?



$N_A = 10^{15}$

$I_E = I_{s,E}\, e^{V_{BE}/V_{TH}}$

I_B = recombination + h^+ of I_E e^-

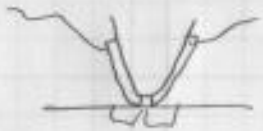
I_C gets majority of I_E

$\approx I_E$ - recombination

$I_C = \beta I_B$

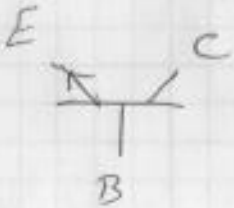
$\beta \approx 10 - 1000$

1st BJT Bardeen Brattain, Shockley



BASE

symmetric



today

not symmetric

lateral bipolar in CMOS is similar

$$I_c = I_s e^{\frac{V_{BE}}{V_{TH}}}$$

$$g_m = \frac{\partial I_c}{\partial V_{BE}} = \frac{1}{V_{TH}} I_s e^{\frac{V_{BE}}{V_{TH}}} = \frac{I_c}{V_{TH}}$$

$r_o = ?$

$$J_{n,base} = q D_n \frac{dn}{dx} = q D_n \frac{n_{po} e^{V_{BE}/V_{TH}}}{W}$$

$$n \sim n_0 e^{V_{BE}/V_{TH}}$$

$$dx = W_B$$

W_B depends on reverse biased CB

linearize the nonlinear physics $\left(\sqrt{\varphi_0 + V_{CB}}\right)$

$$I_c = I_s e^{V_{BE}/V_{TH}} \left(1 + \frac{V_{BE}}{V_A}\right)$$