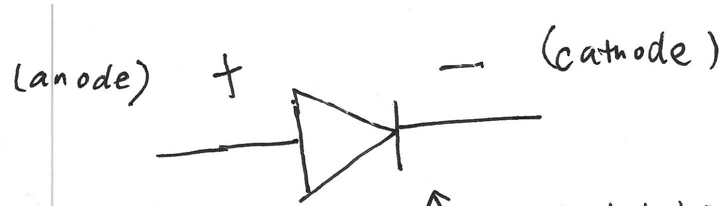
EE 331 Spring 2014
Homework #2 Solutions

Problem 1

1.

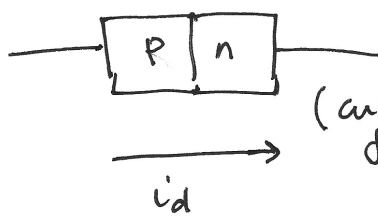
a.



↑notice that looks like a "−" sign so you won't forget it's the cathode

Anode is p-doped
Cathode is n-doped

b.



(current flows from + to −)

c. Reverse bias current

Problem 2

3.1

$$\phi_j = V_T \ln\frac{N_A N_D}{n_i^2} = (0.025V)\ln\frac{(10^{19}\cdot cm^{-3})(10^{18}\cdot cm^{-3})}{10^{20}\cdot cm^{-6}} = 0.979V$$

$$w_{do} = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\phi_j} = \sqrt{\frac{2(11.7\cdot 8.854x10^{-14}F\cdot cm^{-1})}{1.602x10^{-19}C}\left(\frac{1}{10^{19}cm^{-3}}+\frac{1}{10^{18}cm^{-3}}\right)(0.979V)}$$

$$w_{do} = 3.73 \text{ x } 10^{-6} cm = 0.0373 \mu m$$

$$x_n = \frac{w_{do}}{1+\frac{N_D}{N_A}} = \frac{0.0373\mu m}{1+\frac{10^{18}cm^{-3}}{10^{19}cm^{-3}}} = 0.0339\ \mu\text{m} \ \mid\ x_p = \frac{w_{do}}{1+\frac{N_A}{N_D}} = \frac{0.0373\mu m}{1+\frac{10^{19}cm^{-3}}{10^{18}cm^{-3}}} = 3.39 \text{ x } 10^{-3}\ \mu\text{m}$$

$$E_{MAX} = \frac{qN_A x_p}{\varepsilon_s} = \frac{(1.60x10^{-19}C)(10^{19}cm^{-3})(3.39x10^{-7}cm)}{11.7\cdot 8.854x10^{-14}F/cm} = 5.24 \text{ x } 10^5\frac{V}{cm}$$

Problem 3

3.17

$$T = \frac{qV_T}{k} = \frac{1.60x10^{-19}C(0.025V)}{1.38x10^{-23}J/K} = 290\ K$$

Problem 4

4. Total current in a device is the sum of drift and diffusion currents for the two types of carriers: electrons and holes.

Drift current happens whenever there is an electric field (built-in or external).

The direction of the drift current depends on the direction of electric field.

Diffusion current is due to the random thermal motion of carriers. Diffusion happens when there is a gradient (change with respect to location) of the carrier concentrations.

The electron diffusion current is the direction of the gradient (derivative in 1D), but the hole diffusion current is in opposite direction to the gradient (positive carriers down the slope).

Under equilibrium conditions, drift current and diffusion currents are equal and opposite (for each carrier), so the total current is zero.

Problem 5

Oops, didn't actually assign a Problem 5, so everyone gets an A+ on this question.

Problem 6

6. A. E : ~~[illegible]~~ Electric field

B. φ : Built-in Voltage

C. ρ : Charge density

1D Poisson's equation
(from lecture 6 slide #3):

$$\frac{d^2\varphi}{dx^2} = -\frac{dE}{dx} = -\frac{\rho}{\varepsilon}$$

Notice how you integrate the curves as you go from

$$\rho \longrightarrow E \longrightarrow \varphi$$

which is just another way to look at 1D Poisson equation.

Problem 7

3.28

$V_D = nV_T \ln\left(1+\frac{I_D}{I_S}\right)$ | $10^{-14} \le I_S \le 10^{-12}$ | $V_D = (0.025V)\ln\left(1+\frac{10^{-3}A}{10^{-12}A}\right) = 0.518\ V$

$V_D = (0.025V)\ln\left(1+\frac{10^{-3}A}{10^{-14}A}\right) = 0.633\ V$ | So, $0.518\ V \le V_D \le 0.633\ V$

Problem 8

5. J&B P3.33

(a) At 30°C, $V_T = 26\ mV$

$$v_D = V_T ln\left(\frac{i_D}{I_S}+1\right) = 0.754\ V$$

(b) Now the temperature is 50°C, $\Delta T = 20\ K$, then

$$\Delta v_D = \Delta T \frac{dv_D}{dT} = -36\ mV$$

$$v_D(50°C) = v_D(30°C) + \Delta v_D = 0.718\ V$$

Problem 9

6. J&B P3.40

The potential drop across the diode is just the area of the triangle in $E(x)$ plot, we have

$$\phi_j + v_R = \frac{1}{2} w_d E_{MAX}$$

$$E_{MAX} = \frac{2(\phi_j + v_R)}{w_d}$$

$$\frac{w_d}{w_{d0}} = \sqrt{1 + \frac{v_R}{\phi_j}}$$

$$E_{MAX} = \frac{2(\phi_j + v_R)}{w_{d0}\sqrt{1 + \frac{v_R}{\phi_j}}} = \frac{2\sqrt{(\phi_j + v_R)\phi_j}}{w_{d0}}$$

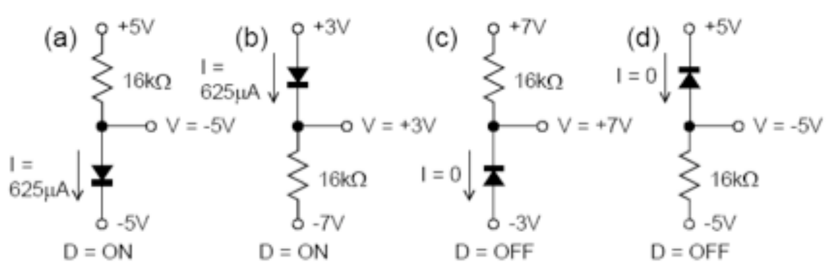
Then

$$v_R = \frac{\left(\frac{w_{d0}E_{MAX}}{2}\right)^2}{\phi_j} - \phi_j = 374.4\ V$$

Problem 10

10. J&B P3.72 (a,b). Work all 4 diode circuits (a – d). State whether each diode is ON or OFF.

(a) ideal diode model



(b) constant voltage drop diode model with $V_{on} = 0.7\ V$