Final Exam

Wednesday, December 8, 2021 11:21 AM

"I pledge my honor I have abided by the Stevens Honor system." - Alex Gaskins

1. A silicon p+n junction has doping concentrations of $Na = 2 \times 10^{17}$ cm^{-3} and $N_d = 2 \times 10^{15}$ cm^{-3}. The cross-sectional area is 10^{-5} cm^2. Calculate (*a*) V_{bi} and (*b*) the junction capacitance at (*i*) $V_R = 1$ V, (*ii*) $V_R = 3$ V, and (*iii*) $V_R = 5$ V. (*c*) Plot $1/C^2$ versus V_R and show that the slope can be used to find N_d and the intercept at the voltage axis yields V_{bi}.

A.) $V_{bi} = (0.0257) \ln\left(\frac{2\times10^{17}(2\times10^{15})}{(1.5\times10^{10})^2}\right) = 0.7305$ V.

B.) $C = AC' = A\sqrt{\frac{e\epsilon_s N_d}{2(V_{bi}+V_R)}} = (10^{-5})\sqrt{\left[\frac{1.6\times10^{-19}}{2(V_{bi}+V_R)}\right](11.7)(8.85\times10^{-14})(2\times10^{15})}$

$C = \frac{1.287\times10^{-13}}{\sqrt{V_{bi}+V_R}}$

[i] $V_R = 1$ V

$\therefore C = 9.783\times10^{-14}$ F

[ii]

$V_R = 3$ V

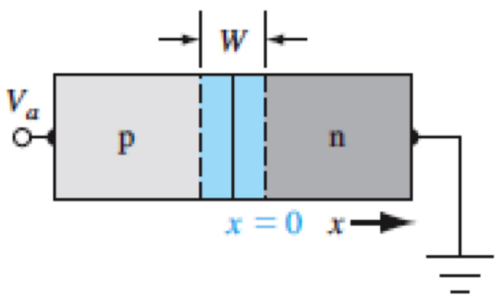
$\therefore C = 6.663\times10^{-14}$ F

[iii]

$V_R = 5$ V

$\therefore C = 5.376\times10^{-14}$ F

2. Consider the ideal long silicon pn junction shown in the Figure below. T =300 K. The n region is doped with 10^{16} donor atoms per cm^3 and the p region is doped with 5 $x10^{16}$ acceptor atoms per cm3. The minority carrier lifetimes are τ_{n0} =0.05 μs and τ_{p0} =0.01 μs. The minority carrier diffusion coefficients are D_n 23 cm^2 /s and D_p =8 cm2 /s. The forward-bias voltage is V_a _=0.610 V. Calculate (*a*) the excess hole concentration as a function of x for $x \geq 0$, (*b*) the hole diffusion current density at x =3 $x10^{-4}$ cm, and (*c*) the electron current density at x =3 $x10^{-4}$ cm.



A.) $$\Delta p_n = P_n - P_{no} = P_{no}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]\exp\left(\frac{-x}{L_p}\right)$$

$$P_{no} = \frac{n_i^2}{N_d} = \frac{(1.5\times10^{10})^2}{10^{16}} = 2.25\times10^4 / cm^3$$

$$L_p = \sqrt{D_p \tau_{po}} = \sqrt{8(0.01\times10^{-6})} = 2.828\times10^{-4}\ cm$$

$$\boxed{\Delta p_n = (3.81\times10^{14})\exp\left(\frac{-x}{2.828\times10^{-4}}\right) / cm^3}$$

B.) $$J_p = -eD_p\frac{d(\Delta p_n)}{dx} = \frac{eD_p(3.808\times10^{14})}{2.828\times10^{-4}}\exp\left(\frac{-x}{2.828\times10^{-4}}\right)$$

For $x = 3\times10^{-4}$ cm

$$J_p = \frac{(1.6\times10^{-19})(8)(3.808\times10^{14})}{2.828\times10^{-4}}\exp\left(\frac{-3}{2.828}\right)$$

$$\boxed{J_p = 0.5966\ A/cm^2}$$

c.) $J_{n_0} = \dfrac{eD_n n_{p0}}{L_n} \exp\left(\dfrac{V_a}{V_t}\right)$

$n_{p0} = 4.5\times10^3/cm^3 \quad L_n = 10.72\ \mu m$

$$J_{n_0} = \frac{(1.6\times10^{-19})(223)(4.5\times10^3)}{10.72\times10^{-4}} \exp\left(\frac{0.610}{0.0259}\right)$$

$$\boxed{J_{n0} = 0.2615\ A/cm^2}$$

3. Consider a GaAs pn junction diode with a cross-sectional area of A= 2x10^{-4} cm^2 and doping concentrations of $N_a = N_d$ = 7x 10^{16} cm^{-3}. The electron and hole mobility values are μ_n =5500 cm^2/V-s and $\mu_{p=}$220 cm^2/V-s, respectively, and the lifetime values are $\tau_0 = \tau_{n0} = \tau_{p0}$ =2x10^{-8} s. (*a*) Calculate the ideal diode current at a (*i*) reverse-biased voltage of V_R= 3 V, (*ii*) forward-bias voltage of V_a = 0.6 V,(*iii*) forward-bias voltage of V_a = 0.8 V, and (*iv*) forward-bias voltage of V_a =1.0 V. (*b*) (*i*) Calculate the generation current at V_R = 3 V. Assuming the recombination current extrapolated to V_a =0 is I_{ro} =6 x10^{-14} A, deter+ine the generation current at (*ii*) V_a=0.6 V, (*iii*) V_a = 0.8 V, and (*iv*) V_a =1.0 V.

$D_n = \left(\dfrac{kT}{e}\right)\mu_n = (0.0259)(5500) = 142.5\ cm^2/s$

$D_p = (0.0259)(220) = 5.70\ cm^2/s$

A.)

$(i)\ I_s = Aen_i^2 \left[\dfrac{1}{N_a}\sqrt{\dfrac{D_n}{\tau_{n0}}} + \dfrac{1}{N_d}\sqrt{\dfrac{D_p}{\tau_{p0}}}\right]$

[i] $I_S = Aen_i^2\left[\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{n0}}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right]$

$$= (2\times10^{-4})(1.6\times10^{-19})(1.8\times10^{6})^2\left[\frac{1}{7\times10^{16}}\sqrt{\frac{142.5}{2\times10^{-8}}} + \frac{1}{7\times10^{16}}\sqrt{\frac{5.70}{2\times10^{-8}}}\right]$$

$$\boxed{I_S = 1.50\times10^{-22}\ A}$$

[ii] $I_D = I_S \exp\left(\frac{V_a}{V_t}\right) = (1.50\times10^{-22})\exp\left(\frac{0.6}{0.0259}\right)$

$$\boxed{I_D = 1.726\times10^{-12}\ A}$$

[iii] $I_D = (1.50\times10^{-22})\exp\left(\frac{0.8}{0.0259}\right) = \boxed{3.896\times10^{-9}\ A}$

[iv] $I_D = (1.50\times10^{-22})\exp\left(\frac{1.0}{0.0259}\right) = \boxed{8.795\times10^{-6}\ A}$

B.) $I_{gen} = \frac{Aen_i W}{2\tau_0}$

$$V_{bi} = (0.0259)\ln\left[\frac{(7\times10^{16})(7\times10^{16})}{(1.8\times10^{6})^2}\right] = \boxed{1.263\ V}$$

$$W = \sqrt{\frac{2(13.1)(8.85\times10^{-14})(1.263+3)}{1.6\times10^{-19}}\left[\frac{7\times10^{16}+7\times10^{16}}{(7\times10^{16})(7\times10^{16})}\right]}$$

$$\boxed{W = 4.201 \times 10^{-5} \text{ cm}}$$

[i]

$$I_{gen} = \frac{(2\times10^{-4})(1.6\times10^{-19})(1.5\times10^{10})(4.201\times10^{-5})}{2(2\times10^{-8})}$$

$$\boxed{I_{gen} = 6.049\times10^{-14} \text{ A}}$$

[ii]

$$I_{rec} = I_{ro}\exp\left(\frac{V_a}{2V_t}\right) = (6\times10^{-14})\exp\left(\frac{0.6}{2(0.0259)}\right)$$

$$\boxed{I_{rec} = 6.436\times10^{-9} \text{ A}}$$

[iii] $$I_{rec} = (6\times10^{-14})\exp\left(\frac{0.8}{2(0.0259)}\right) = \boxed{3.058\times10^{-7} \text{ A}}$$

[iv] $$I_{rec} = (6\times10^{-14})\exp\left(\frac{1.0}{2(0.0259)}\right) = \boxed{1.453\times10^{-5} \text{ A}}$$

4. Consider a silicon PIN photodiode exposed to sunlight. Calculate the intrinsic region width so that at least 90 percent of all photons with wavelengths $\lambda \leq 1$ μm are absorbed in the intrinsic region. Neglect any absorption in the p+ or n+ regions.

Minimum α at $\lambda = 1\,\mu$m, yielding $\alpha = 100$/cm

$$\frac{\phi(x)}{\phi_0} = \exp(-\alpha x) = 0.10$$

or $$\exp(+\alpha x) = \frac{1}{0.10} = 10$$

$$\text{So} \quad x = \frac{1}{\alpha} \ln(10) = \frac{1}{100} \ln(10) = 2.30 \times 10^{-2} \text{ cm}$$

or $230 \ \mu m$

5. A MOS device with an aluminum gate is fabricated on a p-type silicon substrate. The oxide thickness is t_{ox}=22 nm= 220 Å and the trapped oxide charge is Q'_{SS}= 4 x10^{10} cm^{-2}. The measured threshold voltage is V_T=+0.45 V. Determine the p-type doping concentration.

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{(3.9)(8.85 \times 10^{-14})}{220 \times 10^{-8}}$$

$$= 1.569 \times 10^{-7} \text{ F/cm}^2$$

$$Q'_{ss} = (1.6 \times 10^{-19})(4 \times 10^{10}) = 6.4 \times 10^{-9} \text{ C/cm}^2$$

let $N_a = 4 \times 10^{16} / \text{cm}^3$ via trial and error

$$\phi_{fp} = (0.0259) \ln\left(\frac{4 \times 10^{16}}{1.5 \times 10^{10}}\right) = 0.3832 \text{ V}$$

$$x_{dT} = \sqrt{\frac{4(11.7)(8.85 \times 10^{-14})(0.3832)}{(1.6 \times 10^{-19})(4 \times 10^{16})}} = 1.575 \times 10^{-5} \text{ cm}$$

$$|Q'_{SD}(\text{max})| = (1.6 \times 10^{19})(4 \times 10^{16})(1.575 \times 10^{-5})$$

$$= 1.008 \times 10^{-7} \text{ C/cm}^2$$

$$\phi_{ms} \cong -0.94 \text{ V}$$

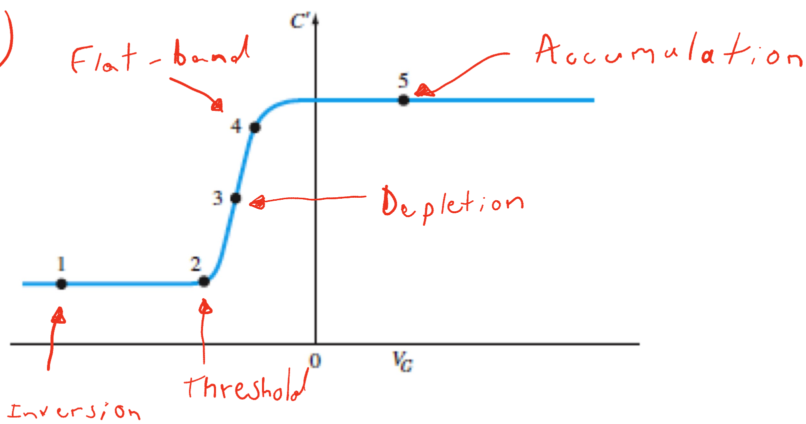
$$V_{TN} = \frac{|Q'_{SD}(max)| - Q'_{ss}}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$$

$$= \frac{1.008 \times 10^{-7} - 6.4 \times 10^{-9}}{1.569 \times 10^{-7}} - 0.94 + 2(0.3832)$$

$$V_{TN} = 0.428 \text{ V} \cong 0.45 \text{ V}$$

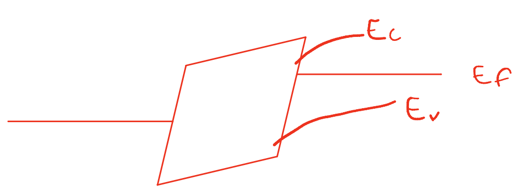
6. Consider the high-frequency C–V plot shown in Figure P10.31. (*a*) Indicate which points correspond to fl at-band, inversion, accumulation, threshold, and depletion modes. (*b*) Sketch the energy-band diagram in the semiconductor for each condition.

A.)



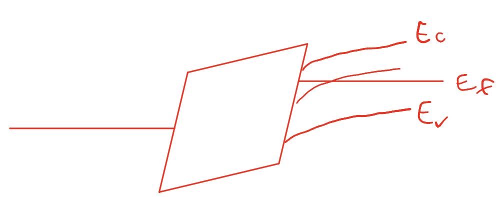
B.)

1.)



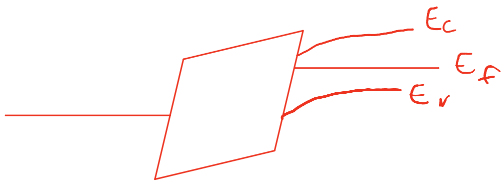
Inversion

2.)



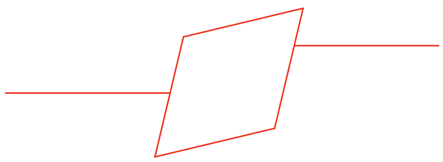
threshold

3.)



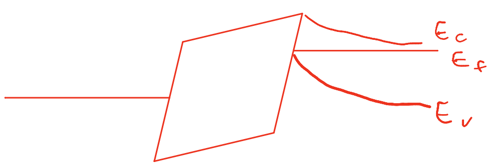
Depletion

4.)



Flat Band

5.)



Accumulation

7. Consider an n-channel MOSFET with the following parameters: $k_n' = 0.18$ mA/V^2, $W/L = 8$, and $V_T = 0.4$ V. Determine the drain current I_D for (*a*) $V_{GS} = 0.8$ V, $V_{DS} = 0.2$ V; (*b*) $V_{GS} = 0.8$ V, $V_{DS} = 1.2$ V; (*c*) $V_{GS} = 0.8$ V, $V_{DS} = 2.5$ V; and (*d*) $V_{GS} = 1.2$ V, $V_{DS} = 2.5$ V

A.) $$I_D = \frac{k_n'}{2}\left[\frac{W}{L}\right]\left(2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right)$$

$$= \left(\frac{0.18}{2}\right)(8)\left[2(0.8 - 0.4)(0.2) - (0.2)^2\right]$$

$$\boxed{= 0.0864 \text{ mA}}$$

B.) $$I_D = \frac{\mu_n'}{2}\left[\frac{W}{L}\right](V_{GS} - V_T)^2$$

$$= \left(\frac{0.18}{2}\right)(8)(0.8 - 0.4)^2$$

$$\boxed{= 0.1152 \text{ mA}}$$

C.) $$I_D = \frac{\mu_n'}{2}\left[\frac{W}{L}\right](V_{GS} - V_T)^2$$

$$= \left(\frac{0.18}{2}\right)(8)(0.8 - 0.4)^2$$

$$\boxed{= 0.1152 \text{ mA}}$$

(V_{DS} has no effect in this case)

D.) $$I_D = \frac{\mu_n'}{2}\left[\frac{W}{L}\right](V_{GS} - V_T)^2$$

$$= \left(\frac{0.18}{2}\right)(8)(1.2 - 0.4)^2$$

$$\boxed{= 0.4608 \text{ mA}}$$

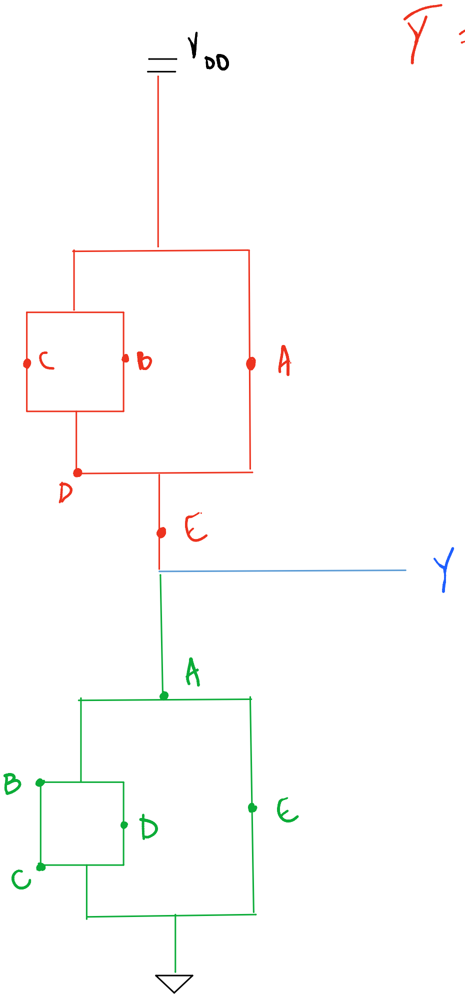
8. (a) Sketch a transistor-level schematic for a single-stage compound CMOS logic gate for the following function:

$$Y = \overline{(A.(C.B + D) + E)}$$

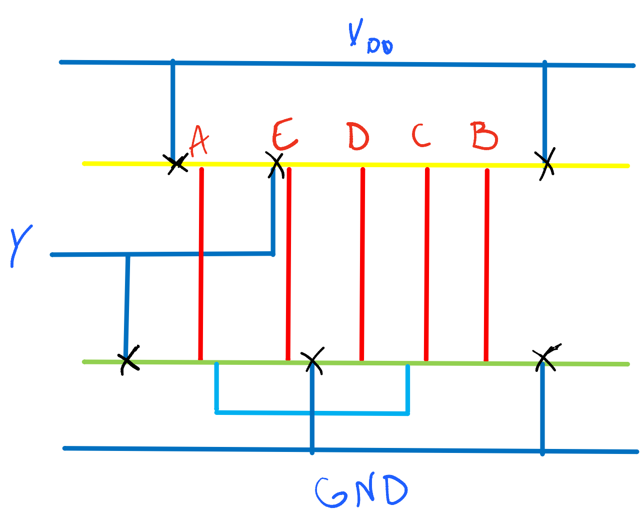
(b)Draw a stick diagram to show the topology of a possible layout

A.)

$\bar{Y} = A + ((C+B).D).E$



B.)



Connects drain from A to