ECE 230L, Final Exam
Fall 2017

"Create the Final Exam" Project

Rules (read and follow them thoroughly!):

1) You must work in the group in which you are assigned below. Separate into your group and get to work on creating your exam problem.
2) You must create one exam problem on the given topic for your group (if you have time remaining, you are welcome to create additional exam problems for any other topical areas but your primary requirement is to create the one that you are assigned).
3) FORMAT: The problem you create should be in the same style & format as the problems from Exams 1 and 2. One page. Multiple parts. Space for performing calculations if needed.
4) EQUATIONS: The equation sheet for the final exam is given on the back of this sheet. If your problem requires equations or constants not on this sheet, then you will need to provide them in the problem statement.
5) DIFFICULTY LEVEL: Your problem should not be ridiculously easy, but it also should not be too difficult. If I can't solve it, then I'm definitely not going to use it on the Final Exam! You should try and match the difficulty level of problems from Exams 1 and 2.
6) TEMPLATE: I highly recommend that you use the "Final Exam Problem Template" that I posted to Piazza. Doing so will increase the chances of your problem being on the actual Final Exam. Be sure to include your Group Name in the given place on the template.
7) SOLUTION: You do not need to provide a solution, but if you do that would be great.
8) I am here to help, so you can ask for guidance or ideas or whatever.
9) **By the end of this lecture**, one member of your group needs to email me (aaron.franklin@duke.edu) your final exam problem. Be sure to indicate the group name in the subject line of the email.

Next Steps

- I will post a PDF file containing all of the created Final Exam problems by Tuesday night (12/5).
- At least one of these created problems will be used on the Final Exam (maybe more if you do a good job with making reasonable and creative problems!).
- We will have the review for the Final Exam during our final lecture on Thursday (12/7) and can go over any of these problems, though I cannot guarentee that I will have had the chance to go through each of them on my own by then.

GROUPS:

1) Crystal Structure & Quantum Theory of Solids
Anning, Sakura
Jerles, Nick
Sun, Yue

2) Thermal Equilibrium
Avlani, Manav
Kaiser, Joe
Sanchez, Judith

3) Semiconductor Band Diagrams
Bei, Webster
Kethireddy, Siddarth
Wang, Michael

4) Carrier Transport
Briere, Maddy
Lebbos, Andres
Welton, Ben

5) pn Junction Diodes
Chen, Xingyu
Liu, Haizhou
Willetts, Walker

6) MOS Capacitors
Culbert, Alex
Lu, Yiliang
Xu, Stephen

7) MOSFETs - 1
Dalla Rosa, Brandon
Nagenalli, Trishul
Xu, Yang

8) MOSFETs – 2
Dhar, Neil
Ndhlala, Justin
Yang, Andy

9) Inverters
Fleeting, Chance
Ning, August
Yang, Jing

10) CMOS Digital Logic
Goldman, Greg
Philippe, Juan
Yin, Frank

11) Linear Amplifiers
Heda, Ritwik
Prematilleke, Savini
Yu, Bill

12) Op-Amps
Huynh, Gordon
Ruiz, Rich
Zapata, Alex

Equation Sheet (tear off and keep with you)

General Semiconductor:

$E = \frac{\hbar^2 k^2}{2m^*}$ $v = \frac{1}{\hbar}\frac{dE}{dk}$ $m^* = \hbar^2\left(\frac{d^2E}{dk^2}\right)^{-1}$ $n_0 = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2}$ $p_0 = \frac{N_a - N_d}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2}$ $f(E) = \frac{1}{1 + e^{\left(\frac{E - E_F}{kT}\right)}}$

$n_0 = n_i e^{\left(\frac{(E_F - E_{Fi})}{kT}\right)}$ $p_0 = n_i e^{\left(\frac{(E_{Fi} - E_F)}{kT}\right)}$ $n_i^2 = N_C N_V e^{\left(\frac{-E_g}{kT}\right)} = n_0 p_0$ $V = IR$ $L_{n,p} = \sqrt{D_{n,p}\tau_{n,p}}$ $h = \frac{na}{A}, k = \frac{na}{B}, l = \frac{na}{C}$

$J_{drift} = \sigma E$ $\sigma = e(\mu_n n + \mu_p p) = \frac{1}{\rho}$ $J_{diff} = eD_n\frac{dn}{dx} - eD_p\frac{dp}{dx}$ $J = \frac{I}{A}$ $\frac{D}{\mu} = \frac{kT}{e}$ $\mu = \frac{e\tau_c}{m_c^*} = \frac{g_m L^2}{V_{DS}C_{ox}}$

pn Junctions:

$V_{bi} = \frac{kT}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right)$ $x_n = \left[\frac{2\varepsilon_s\varepsilon_0}{e}\frac{N_a}{N_d(N_a + N_d)}V_{bi}\right]^{1/2}$ $x_p = \left[\frac{2\varepsilon_s\varepsilon_0}{e}\frac{N_d}{N_a(N_a + N_d)}V_{bi}\right]^{1/2}$

$W = \left[\frac{2\varepsilon_s\varepsilon_0}{e}\frac{N_a + N_d}{N_a N_d}V_{bi}\right]^{1/2}$ $W_{RB} = \left[\frac{2\varepsilon_s\varepsilon_0}{e}\frac{N_a + N_d}{N_a N_d}(V_{bi} + V_R)\right]^{1/2}$ $n_p(-x_p) = n_{p0}e^{\left(\frac{eV_a}{kT}\right)}$ $p_n(x_n) = p_{n0}e^{\left(\frac{eV_a}{kT}\right)}$

$\delta n_p(x) = n_{p0}\left[e^{\left(\frac{eV_a}{kT}\right)} - 1\right]e^{\left(\frac{x_p + x}{L_n}\right)}$ $\delta p_n(x) = p_{n0}\left[e^{\left(\frac{eV_a}{kT}\right)} - 1\right]e^{\left(\frac{x_n - x}{L_p}\right)}$ $E_{Fn} = E_{Fi} + kT\ln\left(\frac{n}{n_i}\right)$ $E_{Fp} = E_{Fi} - kT\ln\left(\frac{p}{n_i}\right)$

$J_{ID} = J_S\left(e^{\left(\frac{eV_a}{kT}\right)} - 1\right)$ $J_S = \frac{eD_p p_{n0}}{L_p} + \frac{eD_n n_{p0}}{L_n}$ $J_{rec} = \frac{eWn_i}{2\tau_0}e^{\left(\frac{eV_a}{2kT}\right)}$ $g_d = \frac{1}{r_d} = \frac{I_{DQ}}{V_t}$ $C_d = \frac{1}{2V_t}\left(I_{p0}\tau_{p0} + I_{n0}\tau_{n0}\right)$

MOS Capacitors:

$C'(acc) = C_{ox} = \frac{\varepsilon_{ox}\varepsilon_0}{t_{ox}}$ $C'(depl) = \frac{\varepsilon_{ox}\varepsilon_0}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)x_d}$ $C'_{\min} = \frac{\varepsilon_{ox}\varepsilon_0}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)x_{dT}}$ $C'_{FB} = \frac{\varepsilon_{ox}\varepsilon_0}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)\sqrt{V_t\left(\frac{\varepsilon_s\varepsilon_0}{eN_{a,d}}\right)}}$

$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}$ $e\phi_s = E_{Fi}\big|_{bulk} - E_{Fi}\big|_{surf}$ $V_{TN} = \frac{\left|Q'_{SD}(\max)\right|}{C_{ox}} + V_{FB} + 2\phi_{fp}$ $V_{TP} = \frac{-\left|Q'_{SD}(\max)\right|}{C_{ox}} + V_{FB} - 2\phi_{fn}$

p-type: $\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} + \phi_{fp}\right)$ $\phi_{fp} = V_t\ln\left(\frac{N_a}{n_i}\right)$ $x_d = \left(\frac{2\varepsilon_s\varepsilon_0\phi_s}{eN_a}\right)^{1/2}$ $x_{dT} = \left(\frac{4\varepsilon_s\varepsilon_0\phi_{fp}}{eN_a}\right)^{1/2}$ $\left|Q'_{SD}(\max)\right| = eN_a x_{dT}$

n-type: $\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} - \phi_{fn}\right)$ $\phi_{fn} = V_t\ln\left(\frac{N_d}{n_i}\right)$ $x_d = \left(\frac{2\varepsilon_s\varepsilon_0\phi_s}{eN_d}\right)^{1/2}$ $x_{dT} = \left(\frac{4\varepsilon_s\varepsilon_0\phi_{fn}}{eN_d}\right)^{1/2}$ $\left|Q'_{SD}(\max)\right| = eN_d x_{dT}$

MOSFETs:

$g_m = \frac{\delta I_D}{\delta V_{GS}}$ $SS = \left(\frac{\delta(\log(I_D))}{\delta V_{GS}}\right)^{-1}$ $f_T = \frac{g_m}{2\pi(C_{gsT} + C_M)} = \frac{g_m}{2\pi C_G}$ $C_M = C_{gdT}(1 + g_m R_L)$

p-type: $I_D = \frac{W\mu_p C_{ox}}{2L}\left[2(V_{SG} + V_T)V_{SD} - V_{SD}^2\right]$ $I_D(sat) = \frac{W\mu_p C_{ox}}{2L}(V_{SG} + V_T)^2$ $K_p = \frac{W\mu_p C_{ox}}{2L}$ $k'_p = \mu_p C_{ox}$

n-type: $I_D = \frac{W\mu_n C_{ox}}{2L}\left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right]$ $I_D(sat) = \frac{W\mu_n C_{ox}}{2L}(V_{GS} - V_T)^2$ $K_n = \frac{W\mu_n C_{ox}}{2L}$ $k'_n = \mu_n C_{ox}$

$k = 8.62x10^{-5}eV/K = 1.38x10^{-23}J/K$ $h = 4.14x10^{-15}eV\cdot s = 6.63x10^{-34}J\cdot s$ $\hbar = \frac{h}{2\pi}$

$q = 1.602x10^{-19}C$ Si at T = 300 K: n_i = 1.5x10^{10} cm^{-3}, E_g = 1.12 eV, ε_s = 11.7 SiO_2: ε_{ox} = 3.9

kT = 0.026 eV at room temperature ε_0 = 8.85x10^{-14} F/cm