EE Diagnostic Exam
Preparation Guide for the Exam Based on
EE 5340 – Semiconductor Device Theory

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Course Learning Goals and Objectives: Introduction to solid state physics and the physics of semiconductor devices. Device physics as applied to diodes, bipolar junction transistors and MOS transistors. Silicon and III-V device physics and technology will be considered.

Text: [R]*Device Electronics for Integrated Circuits*, 3rd ed., by Richard S. Muller, Theodore I. Kamins, and Mansun Chan, John Wiley and Sons, New York, 2003. ISBN: 0-471-59398-2. (Books on reserve in the Science and Engineering Library are marked [R].)

Reference Text: [R]*Devices for Integrated Circuits: Silicon and III-V Compound Semiconductors*, by H. Craig Casey, Jr., John Wiley & Sons, New York, 1999.

Problems: The problem assignments given in the outline below have been selected from the Muller, Kamins and Chan text for preparation for the 5340 Diagnostic Exam. The study of the problems assigned will be helpful in your preparation. (A copy of the Solution Manual is on reserve in the Science and Engineering Library.)

Sample 5340 Diagnostic Exam: A sample exam is attached.

Topic Coverage
Ch. 1 - Semiconductor Electronics, P1:1,3,4,6,8,18
Appendix 1A - Electric Fields …
Ch. 2 - Silicon Technology, P2:15,18,19,20
Ch. 3 - Metal-Semiconductor Contacts, P3:2,3,4,5,7,16
Ch. 4 - *pn* Junctions, P4:1,2,5,6,9,14
Ch. 5 Currents in pn Junctions - P5:1,2,3,6,9,11,19,21
Ch. 6 - Bipolar Transistors I, P6:1,5,8,9,12,13,16,17
Ch. 7 - Bipolar Transistors II, P7:1,2,7,9,11,23,29
Ch. 8 - Properties of the MOS System, P8:1,2,4,7,12,15
Ch. 9 - MOSFETs I, P9:1,3,5,7,14,21,
Ch. 10 - MOSFETs II, P10:1,2,4,8

Diagnostic Exam for EE 5340 (place exam ID # sticker here)
Spring 2008

Instructions, Notes and Physical Constants:

1. Do your own work. Do 2 of the 3 problems.
2. Calculator allowed.
3. You may NOT share a calculator with another student.
4. Use values for constants given on this cover sheet. If a value is not given, explicitly state definitions and assumptions that you use.
5. Special note: Where used, nEm = nx10^m = n·10^m.
6. In some cases, parameters may be calculated from model equations given below .
7. Do all calculations on this exam paper, or on extra sheets supplied by the Graduate Advisor.
8. Use one side of the paper only.
9. Show all calculations, making numerical substitutions and giving numerical results where possible. If time does not permit the final calculation derive the correct symbolic calculation and the correct numerical substitution in the symbolic equation.
10. Write answers in space given.
11. Unless stated otherwise,
    $T = 300$ K, $V_t = 25.852$ mV
12. For this exam purposes, unless otherwise stated, the material is silicon with
    $n_i = 1.07\text{x}10^{10}$ cm^{-3} $N_c = 2.84\text{x}10^{19}$ cm^{-3} $q\chi_{Si} = 4.05$ eV
    $E_{g,Si} = 1.125$ eV. $N_v = 3.08\text{x}10^{19}$ cm^{-3}
13. For the work function of poly-silicon, use
    $\phi_{n+} = \chi_{si} = 4.05$ V
    $\phi_{p+} = \chi_{Si} + E_{g,Si}/q = 5.175$ V.
14. For the minority carrier lifetime in silicon (either electrons or holes), you may use the model relationship
    $\tau_{min} = (45\text{x}10^{-6}\text{ sec})/(1+7.7\text{x}10^{-18}*N_{imp}+4.5\text{x}10^{-36}*N_{imp}^2)$,
    (where N_{imp} = the total impurity concentration in n- or p-type material, compensated or not).
15. For holes in silicon, assume
    $\mu_p = \{425.6\div[1+(N_{imp}\div2.23\text{x}10^{17})^{0.719}]\}+44.9$, in cm^2/V-sec,
    (where N_{imp} = the total impurity concentration in n- or p-type material, compensated or not).
16. For electrons in silicon, assume
    $\mu_n = \{1346\div[1+(N_{imp}\div9.2\text{x}10^{16})^{0.711}]\}+68.5$, in cm^2/V-sec,
    (where N_{imp} = the total impurity concentration in n- or p-type material, compensated or not).
17. Metal gate work functions should be assumed to be
    $\phi_{Au} = 4.75$ V for gold, $\phi_{Al} = 4.1$V for aluminum.
18. The electron affinity of SiO_2 is $\chi_{SiO2} = 0.95$ V.
19. Planck constant $h = 6.62618\text{x}10^{-34}$J-s= $4.1354\text{x}10^{-15}$eV-s, 1 eV = $1.60218\text{x}10^{-19}$ Joule
20. Free electron mass $m_o = 9.1095\text{x}10^{-28}$ g.
21. Boltzmann constant, $k = 1.38066\text{x}10^{-23}$J/K
22. Electron charge, $q = 1.60218\text{x}10^{-19}$ Coulomb
23. Permittivity of free space, $\varepsilon_o = 8.85418\text{x}10^{-14}$ Fd/cm
24. Relative permittivity of silicon, $\varepsilon_{r,Si} = 11.7$
25. Relative permittivity of silicon dioxide, $\varepsilon_{rOx} = 3.9$
26. The breakdown voltage of an abrupt (step) junction (assymetrical or one-sided) diode with doping on the lightly doped side of N_B is $V_B = 60(Eg/1.1)^{3/2}\,(10^{16}/N_B)^{3/4}$ V.
27. Each problem is worth 50 points. Do any 2 of the attached 3 problems.

1. A sample of silicon has donor concentration of 1.500E17/cm^3 and acceptor concentration of 3.3E15/cm^3.

a. What is the electron concentration (to 4 significant figures)?

Answer a: n = _______________ cm^{-3}.

b. What is the total impurity concentration, N_i (to 4 significant figures)?

Answer b: N_i = __________________cm^{-3}.

c. What is the electron mobility?

Answer c: μ_n = __________________ cm^2/V-sec.

d. Sketch and calculate the location of the equilibrium Fermi level for this material relative to the conduction band edge?

Answer d: E_c **-** E_f = ______________ eV

2. For this problem, consider a **hypothetical** semiconductor material with n_i = 8.00E+10/cm^3 and a relative permittivity of 13. Consider the charge neutral region width to be the same as at V_a = 0, unless otherwise stated.

- The anode (p-type) region has N_A = 3.50E+18/cm^3 (no compensation), D_{min} = 7.6 cm^2/sec and τ_{min} = 3E-8 sec, and is 1.4E-4 cm wide from junction to contact.
- The cathode (n-type) region has N_D = 6.8E15/cm^3 (no compensation), D_{min} = 32 cm^2/sec and τ_{min} = 6.2E-6 sec, and is 400E-4 cm wide from junction to contact.

a. Calculate the minority carrier diffusion length, L_p in the cathode.

Answer a: L_p = _______________ cm.

b. For V_a = 650 mV (in the low-level injection range, and ignoring recombination currents), calculate the largest component of the forward diffusion current density at the appropriate depletion region boundary (either $J_p(x_n)$ or $J_n(-x_p)$ in functional notation). Also, sketch the pn junction band diagram at this potential.

Answer b: J(650 mV) = _______________ A/cm^2.

c. For V_a = 0 V the depletion capacitance per unit area (assume a perfectly abrupt junction) is:

Answer c: C'_j(0 V) = _______________ Fd/cm^2.

d. Calculate the minority carrier transit time across the lightly doped side for the condition in part b.

Answer d: τ_{min} = __________________ sec.

3. An ideal (no interface charge) nmos (n+ poly-Si gate) device has substrate concentration of 5.41E14 cm^{-3} and the gate oxide thickness is 740 nm.

a. Calculate the ϕ_{ms} for this device and sketch the band structure for the device at the flat-band condition, including the energy levels in the poly-Si and silicon substrate. Show the value of $q\phi_{ms}$ on this sketch.

Answer a: [6] ϕ_{ms} = ____________________ V.

b. Sketch the band diagram for the silicon at the onset of strong inversion. Be sure to label each level and the total band bending.

Answer b: Show sketch above.

c. Next, calculate the maximum depletion depth at the onset of strong inversion (OSI).

Answer c: $x_{d,max}$ = ____________________ cm.

d. Next, calculate the threshold voltage for channel formation in this system.

Answer d: V_T = ____________________.

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