Test 1-EE 5340/001&051 (print last name) **TEST SOLUTION** (print first name)___________
Thursday, September 25, 2003, 8:00 AM, 206 Activities Building
75 minutes allowed (last four digits of your student #) _____________ (e-mail _if_ new)______________________

Seat Number _______________ Enrolled in (circle one) 8:00 AM or 9:30 AM class

Instructions:

1. Do your own work.
2. DO NOT REMOVE THE STAPLE ON THIS EXAM.
3. You may use either a legal copy of the text OR reference text. You may NOT pass a book or note sheet to another student. You may NOT use class notes. Do not use previously solved problems.
4. Calculator allowed. You may NOT share a calculator with another student.
5. Unless given other values, use values given on this cover sheet. If a value is not given, explicitly state definitions and assumptions that you use.
6. Where possible, calculate parameters rather than read them from a graph.
7. Do all work in the spaces provided on this exam paper. If you write on the back of a sheet, make the notation "PTO" in your solution in order to assure that material written on the back of the page is evaluated for a grade. AN EXTRA BLANK SHEET IS ATTACHED AT THE BACK OF THE EXAM.
8. Show all calculations, making numerical substitutions and giving numerical results where possible.
9. Write answers in space given.
10. Unless stated otherwise,
    T = 300K, V_t = 25.843 mV (to agree with the k and q values in M&K)
11. Unless otherwise stated, the material is silicon (300K) with
    n_i = 1.45E10 cm^{-3} N_c = 2.8E19 cm^{-3} $q\chi_{Si}$ = 4.05 eV
    $E_{g,Si}$ = 1.124 eV. N_v = 1.04E19 cm^{-3}
12. For the work function of poly silicon, use
    $\phi_{n+} = \chi_{si}$ = 4.05 V
    $\phi_{p+} = \chi_{Si} + E_{g,Si}/q$ = 5.174 V.
13. For minority carrier (either electrons or holes) lifetime in silicon, use the relationship
    τ_{min} = (45E-6 sec)/(1+7.7E-18*N_i+4.5E-36*N_i^2),
    where N_i = the total impurity concentration
14. For holes in silicon doped primarily with boron, assume
    μ_p = {470.5÷[1+(N_i÷2.23E17)$^{0.719}$]}+44.9, in cm^2/V-sec.
15. For electrons in silicon doped primarily with phosphorous, assume
    μ_n = {1414÷[1+(N_i÷9.2E16)$^{0.711}$]}+68.5, in cm^2/V-sec.
16. For electrons in silicon doped primarily with arsenic, assume
    μ_n = {1417÷[1+(N_i÷9.68E16)$^{0.68}$]}+52.2, in cm^2/V-sec.
    (In 12 through 16, N_i = the total impurity concentration in n- or p-type material, compensated or not).
17. Metal gate work functions should be assumed to be
    $\phi_{M,Al}$ = 4.1 V for aluminum, $\phi_{M,Pt}$ = 5.3 V for platinum, $\phi_{M,Au}$ = 4.75 V for gold
18. The electron affinity of SiO_2 is χ_{SiO2} = 1.00 V.
19. Planck constant, h = 6.625E-34 J-s = 4.135E-15 eV-s, (1 eV = 1.602E-19 Joule).
20. Free electron mass m_o = 9.11E-28 g.
21. Boltzmann constant, k = 1.38E-23 J/K
22. Electron charge, q = 1.602E-19 Coulomb
23. Permittivity of free space, ε_o = 8.854E-14 Fd/cm
24. Relative permittivity of silicon, ε_r = 11.7
25. Relative permittivity of silicon dioxide, ε_{rOx} = 3.9
26. The breakdown voltage of an abrupt (step) junction (asymmetrical 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 part is worth [x] points, as given in the problem.

1 A boron doped (concentration of 3.5E15/cm^3) wafer is to be used to fabricate a resistor.
a Calculate the majority carrier mobility of this material.

NaB = 3.50E+15 cm^-3
Nim = NaB = 3.5E+15 cm^-3
MUpB = (470.5/(1+(Nim/2.23E17)^0.719))+44.9 cm2/V-sec.
MUpB = (470.5/(1+(3.5e15/2.23E17)^0.719))+44.9
MUpB = 493 cm^2/V-sec.

a [7] $\mu_{\text{majority carriers}}$ = ____________________cm^2/V-sec.

b Next, calculate the majority carrier concentration.

po = NaB = 3.5E+15 cm^-3

b [6] majority carrier concentration = ____________________ cm^{-3}.

c Next, calculate the conductivity of this material.

sigma = po*q*MUpB = 2.76E-01 /(Ohm-cm)

c [6] σ = ____________________(Ohm-cm)$^{-1}$.

d The thickness of the resistor is to be 0.2 micron (1 micron = 1μm = 1E-4 cm). Calculate the resistance for a 10 square resistor (i.e., L = 10W).

L/W = 10
t = 2.00E-05 cm
R = L/(W*t*sigma) = 1.81E+06 Ohms

d [6] R = ____________________Ohm.

2 A sample of silicon has phosphorous concentration 2E15/cm^3, boron concentration of 5E16/cm^3, and arsenic concentration of 3E17/cm^3.
a Calculate the best estimate for the mobility of the majority carriers.

Nim = NaB + NdP + NdAs = 2E15 + 5E16 +3E17 = 3.52E+17 cm^-3
MUnAs= (1417/(1+(Nim/9.68E16)^0.68))+52.2 cm^2/V-sec
MUnAs= 468 cm^2/V-sec

a [6] $\mu_{\text{majority carriers}}$ = ____________________cm^2/V-sec.

b Next, calculate the minority carrier concentration in this material.

no = NdAs + NdP - NaB = 3e17 + 2E15 - 5E16 = 2.52E+17 cm^-3
po = ni^2/no = 834 cm^-3

b [7] minority carrier concentration = ____________________ cm^{-3}.

3 An n-Si Schottky diode is made with a gold (Au) metal electrode on silicon material. The Si has an equilibrium Fermi potential ϕ_n = 324 mV.
a Calculate the "ideal Schottky theory" value for $\phi_{i,ideal}$ for this device.

Phin = 324 mV
PHIi = PHImAu - (CHIsi +Vt*ln(Nc/ni) - PHIn) = 0.471 V

a [6] $\phi_{i,ideal}$ = ____________________ V.

b Next, calculate the electron concentration at equilibrium in this silicon material.

no = ni*exp(PHIn/Vt) = 4.04E+15 cm^-3

b [6] n_o = ____________________ cm^{-3}.

4 The values of n_i = 1.07E10 cm^{-3}, N_c = 2.84E19 cm^{-3}, and N_v = 3.08E19 cm^{-3}, are given for 300K by H. C. Casey in his text. These are obviously not the same as the values given in Mueller and Kamins 3rd edition.
a Calculate the position of the conduction band relative to the intrinsic level which is consistent with Casey.

Ec - Efi = (k*T/q)*ln(Nc/ni) = 561 meV

a [6] $E_C - E_{Fi}$ = ____________________ eV.

b Next, calculate value of E_g at 300Kconsistent with the Casey values quoted in 4a.

Eg = k*T*ln(Nc*Nv/ni^2) = 1.124 eV

b [7] E_g = ____________________.

Return to using the values for constants as given on the cover sheet.
5 A piece of silicon has μ_n = 560 cm^2/V-sec. The only dopant in this silicon is phosphorous.
a Assuming the lattice and impurity mobilities combine according to the ideal theory, calculate the contribution of the mobility due to the impurity scattering.

MUtotal^-1 = MUlattice^-1 + MUn,impurity^-1
MUlattice = 1414 cm^2/V-sec for phosphorous dopants
MUn,impurity = (MUtotal^-1 - MUlattice^-1)^-1 = 927 cm^2/V-sec

a [6] $\mu_{n,impurity}$ = ____________________ cm^2/V-sec.

b Calculate the low field drift velocity for these electrons when an electric field of 1.5E3 V/cm is applied.

vn,drift = MUtotal*E = 560*1.5E3 = 8.40E+05 cm/sec

b [6] $v_{n,drift}$ = ____________________ cm/sec.

6 A p-n step junction has a constant donor concentration of 2.3E17 phosphorous on the n-side and a constant acceptor concentration of 9E15 on the p-side.
a Calculate the built-in voltage, V_{bi}, for this junction.

Vbi = PHIi = (k*T/q)ln(Na*Nd/ni^2) = (k*T/q)*ln(9E15*2.3E17/ni^2)
= 773 mV

a [6] V_{bi} = ____________________ V.

b Calculate the width of the depletion region on the p-side for V_a = -10V.

Neff = Nd*Na/(Nd+Na) = 8.66E+15
Va = -10
xp = (1+Na/Nd)^-1*W = (1+Na/Nd)^-1*sqrt(2*eps0*epsSi*(Vbi-Va)/(q*Neff))
= 1.22E-04 cm

b [7] x_p = ____________________ cm.

7 A silicon Schottky diode has been fabricated with ϕ_i = 760 mV, and $C_j(V_a=0) = C_{j0}$ =120 pFd. Assume the silicon doping concentration is constant through the silicon. (Note: 1 pFd = 1E-12Fd.)
a Calculate the diode capacitance for V_a = -6 V.

Cj = Cj0*(1 - Va/PHIi)^-(1/2) = 120*(1 - (-6)/0.760)^-(1/2)
= 40.2 pFd

a [6] $C_j(V_a=-6)$ = ____________________ Fd.

b Calculate the diode area if the depletion region width at V_a = 0 is 0.75 microns.

Cj = eps0*epsSi*A/W
A = Cj*W/(eps0*epsSi) = 120E-12*0.75E-04/(eps0*epsSi)
A = 8.69E-03 cm^2

b [6] A = ____________________ cm^2.