KEY

Test 2 - EE 5340/001 (print last name) ___________________________ (print first name) ______________________
Thursday, October 29, 2009, 8:00 AM, 108 Nedderman Hall
1 hr 20 min allowed (last four digits of your student #) _____________ (e-mail if new)______________________

Instructions:

1. Do your own work. DO NOT REMOVE THE STAPLE ON THIS EXAM.
2. 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.
3. Calculator allowed. You may NOT share a calculator with another student.
4. Use values given on this cover sheet. If a value is not given, explicitly state definitions and assumptions that you use. In all cases, the notation, mEn = $m\times10^n$.
5. Where possible, calculate parameters rather than read them from a graph.
6. 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.
7. Show all calculations, making numerical substitutions and giving numerical results where possible.
8. Write answers in space given.
9. Unless stated otherwise,
   T = 300K, V_t = 25.843 mV (to agree with M&K k and q values)
10. 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}
11. 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.
12. For minority carrier (either electrons or holes) lifetime in silicon, use the relationship
    τ_{min} = (4.5E-5 sec)/(1 + N_i/1E17 + $(N_i/5E17)^2$),
    where N_i = the total impurity concentration in cm^{-3}
13. 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.
14. 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.
15. For electrons in silicon doped primarily with arsenic, assume
    μ_n = {1417÷[1+$(N_i$÷9.68E16$)^{0.680}$]}+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).
16. 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
17. The electron affinity of SiO_2 is χ_{SiO2} = 1.00 V.
18. Planck constant h = 6.625E-34 J-s = 4.135E-15 eV-s, (1 eV = 1.602E-19 Joule).
19. free electron mass m_o = 9.11E-28 g.
20. Boltzmann constant, k = 1.38E-23 J/K
21. Electron charge, q = 1.602E-19 Coulomb
22. Permittivity of free space, ε_o = 8.854E-14 Fd/cm
23. Relative permittivity of silicon, ε_r = 11.7
24. Relative permittivity of silicon dioxide, ε_{rOx} = 3.9
25. 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. The critical field for breakdown is modeled as $E_{crit} = (120V\cdot qN_B/(\varepsilon_r\varepsilon_0))^{1/2}\cdot(Eg/1.1)^{3/4}\cdot(10^{16}/N_B)^{3/8}$
26. Each part is worth [x] points, as given in the problem.
27. **Turn your cell phone off.**

1. A p-type wafer with $N_{a,Boron}$ = 2E16 cm^{-3}, has a planar diode constructed with a junction to a region with n-type doping which has ϕ_n = 510 mV. There is no compensation in either region.
a. What is the Phosphorous doping concentration in the n^+-region?

Nd = ni*exp(PHIn/Vt)
PHIn = 0.510 V
Nd = 5.39E+18 cm^-3

a. [7] The Phosphorous doping concentration in the n^+-region is N_d = ____________________ cm^{-3}.

b. Find the breakdown voltage (BV) for this diode assuming BV > $\phi_i = V_{bi}$.

Eg = 1.124 eV Na = 2.00E+16 cm^-3
From Casey's equation, BV = 60*(1.124/1.1)^(3/2)*(1E16/Na)^(3/4)
BV = 36.85 V

b. [7] BV = ____________________ V.

c. What is the applied bias on the diode when the depletion width is 2 μm?

xd = sqrt(2*e0*eSi*(PHIi - Va)*(1/Na+1/Nd)/q) = 2.00E-04 cm
Va = -xd^2*(q/(2*e0*eSi*(1/Na+1/Nd))) + PHIi
Va = -60.75 V

c. [7] V_a(W=2 μm) = ____________________ V.

d. What is the built-in voltage, $\phi_i = V_{bi}$?

PHIi = Vt*ln(Na*Nd/ni^2)
PHIi = 0.875 V

d. [7] The built-in voltage, $\phi_i = V_{bi}$ = ____________________ V.

2. For the same diode as given in problem 1(assuming “long diode” conditions, and ignoring the contributions due to the heavily doped side of the junction):
a. Calculate the minority carrier diffusion coefficient in the p-type wafer.

In the p-region (lightly doped side) the following are the case
Dmin = Vt*Mun = Vt*(1414/(1+(Na/9.20E16)^0.711)+68.5)
Dmin = 29.1 cm^2/sec

a. [7] The minority carrier diffusion coefficient is D_{min} = ______________________ cm^2/sec.

b. Calculate the minority carrier diffusion length in the wafer.

TAUmin = 3.75E-05 sec = (4.5E-5 sec)/(1 + Na/1E17 + (Na/5E17)^2)
Lmin = sqrt(Dmin*TAUmin) = 0.0330 cm

b. [7] The minority carrier diffusion length is L_{min} = ______________________ cm.

c. Calculate the minority carrier diffusion saturation current density.

Jdiff,s = q*ni^2*Dmin/(Na*Lmin)
Jdiff,s = 1.48E-12 A/cm^2

c. [7] The minority carrier diffusion saturation current density is $J_{s,min}$ = ______________________ A/cm^2.

d. Calculate the minority carrier recombination saturation current density.

From Eqn 5.3.25 in M&K, for Na << Nd, we have
Jrec,s = Jdiff,s*(xd/(2*ni))*(Na/Ln)
Note that the saturation current density is calculated for Va = 0
xd0 = sqrt(2*e0*eSi*PHIi*(1/Na+1/Nd)/q)
xd0 = 2.38E-05 cm
Jrec,s = 7.392E-10 A/cm^2

d. [7] The minority carrier recombination saturation current density is $J_{s,rec}$ = ___________________ A/cm^2.

3. For the same diode as given in problem 1(assuming "long diode" conditions, and ignoring the contributions due to the heavily doped side of the junction). Also assume the area of the diode is 1E-4 cm^2:
a. Calculate the depletion width, x_d at $V_a = 0$.

xd0 = sqrt(2*e0*eSi*PHIi*(1/Na+1/Nd)/q)
xd0 = 2.38355E-05 cm

a. [7] The depletion width, $x_d(V_a=0) =$ ______________________ cm.

b. Calculate the depletion capacitance C_j at $V_a = 0.55$V.

A = 1.00E-04 cm^2
Cj0 = e0*eSi*A/xd = 4.346E-12 Fd
Cj = Cj0*(1-Va/PHIi)^-0.5
Cj = 7.129E-12 Fd

b. [7] The depletion capacitance $C_j(V_a=0.55V) =$ ______________________ Fd.

c. Accounting for the diffusion current only, calculate the small signal diffusion resistance, r_d at $V_a = 0.55$V.

Id = Jdiffs*A*exp((Va/Vt)-1)
Id = Jdiffs*A*exp((Va/Vt)-1) 9.550E-08 A
rd=Vt/Id= 2.706E+05 Ohm

c. [7] The small signal diffusion resistance, $r_d(V_a=0.55V) =$ ______________________ Ohm.

d. Accounting for the diffusion current only, calculate the small signal diffusion capacitance, C_d at $V_a = 0.55$V.

Cd=TAUmin/rd = 1.38E-10 Fd

d. [7] The small signal diffusion capacitance, $C_d(V_a=0.55V) =$ ______________________ Fd.

4. [16] Now, consider that another diode is fabricated which is identical, except that the charge-neutral-region width on the lightly doped side is reduced to 50E-4 cm. Describe how each of your previous answers will be changed.

1a. **There will be no change.**

1b. **There will be no change.**

1c. **There will be no change.**

1d. **There will be no change.**

2a. **There will be no change.**

2b. **There will be no change.**

2c. **Lmin will be replaced by Lmin*tanh(Wcnr/Lmin)**

2d. **Lmin will be replaced by Lmin*tanh(Wcnr/Lmin)**

3a. **There will be no change.**

3b. **There will be no change.**

3c. **There will be a change since 2c changed.**

3d. **There will be a change since 2c changed.**