Test 1-EE 5340/001&051 (print last name)________________________ (print first name)_______KEY_____________

Tuesday, September 17, 2002, 8:00 AM

75 minutes allowed (last four digits of your student #) ____________ (e-mail <u>if</u> 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 OR ONE sheet of hand-written notes. 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. Explicitly state definitions and assumptions that you use.
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 = 25.852 mV
10. Unless otherwise stated, the material is silicon with n_i = 1.07E10 cm^{-3}, N_c = 2.84E19 cm^{-3}, N_v = 3.08E19 cm^{-3}, $q\chi_{Si}$ = 4.05 eV, and $E_{g,Si}$ = 1.125 eV.
11. For the work function of n+ poly silicon, use $\phi_{n+} = \chi_{si}$ = 4.05 V, and for the work function of p+ poly silicon, use $\phi_{p+} = \chi_{Si} + E_{g,Si}/q$ = 5.175 V.
12. For minority carriers 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) for minority carrier lifetime (either electrons or holes).
13. For holes in silicon, assume μ_p = {418.3÷[1+(N_i÷1.6E17)$^{0.7}$]}+49.7, in cm^2/V-sec (where N_i = the total impurity concentration in n- or p-type material whether compensated or uncompensated).
14. For electrons in silicon, assume μ_n = {1268÷[1+(N_i÷1.3E17)$^{0.91}$]}+92, in cm^2/V-sec (where N_i = the total impurity concentration in n- or p-type material whether compensated or uncompensated).
15. Metal gate work functions should be assumed to be ϕ_{Au} = 4.75 V, ϕ_{Al} = 4.1V.
16. The electron affinity of SiO_2 is χ_{SiO2} = 0.95 V.
17. Each part is worth [x] points, as given in the problem.
18. Planck constant h = 6.62618×10^{-34}J-s= 4.1354×10^{-15}eV-s
19. 1 eV = 1.60218×10^{-19} Joule
20. free electron mass m_o = 9.1095×10^{-28} g.
21. Boltzmann constant, k = 1.38066×10^{-23}J/K
22. Electron charge, q = 1.60218×10^{-19} Coulomb
23. Permittivity of free space, ε_o = 8.85418×10^{-14} Fd/cm
24. Relative permittivity of silicon, ε_r = 11.7 ~~Fd/cm~~

1. A semiconductor (not silicon) with electron effective mass ratio $m^*_n/m_o = 1.1$ is doped with singly ionized donors. Hint: Remember to use MKS units throughout this problem, and then convert the final answer to cm, eV, etc.

a. Calculate the radius of the first Bohr orbit for a conduction electron trapped at an ionized donor site in the ~~silicon~~ *semiconductor* lattice. *You may use 11.7 or 1 for the relative permittivity.*

*ri = (n^2*h^2*er*eo)/(pi*mo*mn/mo*q^2)*

*= (n^2*h^2*er*eo*100)/(pi*mo*0.001*1.1*q^2)*100*

= 5.62861E-08cm, if 11.7 is used for ε_r

= 4.81078E-09cm, if 1 is used for ε_r

Answer a[4]: r_1 = _______________ cm.

b. Calculate the ionization energy required to remove this electron from the first orbit and put it in the conduction band.

*deltaE = q^4*mn/mo*mo/(8*eo^2*h2)*

*= q^4*1.1*mo*0.001/(8*(er*eo*100)^2*h^2)/q*

= 0.109 eV, if 11.7 is used for ε_r

= 14.97 eV, if 1 is used for ε_r

Answer b[4]: $E_i = \Delta E$ = _______________ eV.

c. What is the effective density of states for these electrons in the conduction band (m^*_n=m_c)?

Nc = 2(2*pi*mn/mo*mo*k*T/h^2)^(3/2)*

= 2(2*pi*1.1*mo*0.001*k*T/h^2)^(3/2)*0.000001*

Nc = 2.90E+19 cm^{-3}

Answer c[4]: N_c = _______________ cm^{-3}.

d. If the hole effective mass is the same as the electron effective mass, and the band gap $E_g = E_c - E_v = 1.4$ eV, calculate the intrinsic carrier concentration.

Note that mn = mp gives Nc = Nv, so

*ni = (Nc^2*exp(-1.4*q/(k*T)))^(1/2)*

= 5.04E+07 cm^{-3}

Answer d[4]: n_i = _______________ cm^{-3}.

2. A sample of silicon has donor concentration of 2E17/cm^3 and acceptor concentration of 9E16/cm^3.

a.What is the net donor concentration?

$$N = Nd - Na$$

$$N = \quad 1.1E{+}17\ cm^{-3}$$

Answer a[6]: N = ______________ cm^{-3}.

b. What is the electron concentration?

$$no = N$$

$$no = \quad 1.1E{+}17\ cm^{-3}$$

Answer b[6]: n = ______________ cm^{-3}.

c. What is the hole concentration?

$$po = ni\hat{}2/no$$

$$po = \quad 1041\ cm^{-3}$$

Answer c[6]: p = ______________ cm^{-3}.

d. What is the total impurity concentration, N_i?

$$Ni = Nd + Na$$

$$Ni = \quad 2.9E{+}17\ cm^{-3}$$

Answer d[6]:N_i = _________________cm^{-3}.

e. What is the electron mobility?

$$\mu_n = \{1268 \div [1+(N_i \div 1.3E17)^{0.91}]\}+92\ cm^2/V\text{-}sec$$

$$\mu_n = 504\ cm^2/V\text{-}sec$$

Answer e[7]:μ_n = _________________ cm^2/V-sec.

3. A rectangular region of silicon has p_o = 3E16 cm^{-3} and is 2 μm by 0.5 μm in cross-section and 100 μm long. (1 μm = 1E-4 cm.) There is no compensation of acceptors by donors.

a. What is the hole mobility of this material?

po = 3.00E+16
Na = 3.00E+16
Nd = 0
Ni = 3E+16
μp = {418.3/[1+(Ni/1.6E17)^0.7]}+49.7
= 369 cm^2/V-sec

Answer a[7]:μ_p = __________________ cm^2/V-sec.

b. What is the electron concentration of this material?

no = ni^2/(-N)
no = 3816 cm^-3

Answer b[6]: n_o = __________________ cm^{-3}.

c. What is the resistivity of this material?

*rho = (no*q*μn + po*q*μp)^-1*
*= 1/(po*q*μp), since po >> no*
= 0.564 ohm-cm

Answer c[7]: ρ =_____________________ Ohm-cm.

d. What is the total resistance of this material for current flow along the 100 μm direction?

*R = rho*l/(w*t)*
R = 5.64E+05 ohm

Answer d:[6] R = ____________________ Ohm

e. What is the hole diffusion coefficient for this material?

*Dp = Vt*mup*
Dp = 9.54 cm^2/sec

Answer e[6]: D_p = ____________________ cm^2/sec.

4. A region of silicon has a net donor concentration of 1E18 cm^{-3}.

a. What is the location of the equilibrium Fermi level for this material relative to the conduction band edge?

Nd = no = 1.00E+18 cm^-3
*Ec - Ef = kT*ln(Nc/n)*
Ec - Ef = 86.5 meV

Answer a[7]: E_c - E_f = _____________ eV

b. What is the minority carrier lifetime of this material, assuming that all impurities are donors?

*tmin = [45E-6 sec]/[1+7.7E-18*Ni+4.5E-36*Ni^2]*
Ni = Nd = 1.00E+18 cm^-3
tmin = 3.41E-06 sec

Answer b[7]: τ_{min} = _____________ sec.

c. What are the minority carriers in this material?

Answer c[2]: Circle one: electrons (holes)

d. Is the Maxwell-Boltzmann a reasonable approximation for calculating the answer in part a?

Answer d[2]: Circle one: (yes) no

e[4]. On what basis did you decide the answer to part d?

Ec – Ef > 2kT, so the integration done using the MB approximation for the FD distribution in the carrier population calculation is correct to better than 5%