Test 01-EE 5342/051 (print last name)______________________ (print first name)___**KEY**_______________

Tuesday, February 18, 2003, 9:30 AM, 106 Nedderman Hall

75 minutes 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 ONE sheet of hand-written notes. You may NOT pass a book or note sheet to another student. You may NOT use class notes, nor 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.
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} $q\chi_{Si} = 4.05$ eV
    $E_{g,Si} = 1.125$ eV. $N_v = 3.08E19$ cm^{-3}
11. For the work function of poly silicon, use
    $\phi_{n+} = \chi_{si} = 4.05$ V
    $\phi_{p+} = \chi_{Si} + E_{g,Si}/q = 5.175$ V.
12. For minority carrier (either electrons or holes) lifetime in silicon, use the relationship
    $\tau_{min} = (45E\text{-}6 \text{ sec})/(1+7.7E\text{-}18{*}N_{imp}+4.5E\text{-}36{*}N_{imp}^2)$,
    where N_i = the total impurity concentration
13. For holes in silicon, assume
    $\mu_p = \{418.3\div[1+(N_i\div1.6E17)^{0.7}]\}+49.7$, in cm^2/V-sec
    (where N_i = the total impurity concentration in n- or p-type material, compensated or not).
14. For electrons in silicon, assume
    $\mu_n = \{1268\div[1+(N_i\div1.3E17)^{0.91}]\}+92$, in cm^2/V-sec
    (where N_i = the total impurity concentration in n- or p-type material, compensated or not).
15. Metal gate work functions should be assumed to be
    $\phi_{Au} = 4.75$ V for gold, $\phi_{Al} = 4.1$V for aluminum.
16. The electron affinity of SiO_2 is $\chi_{SiO2} = 0.95$ V.
17. 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
18. free electron mass $m_o = 9.1095\text{x}10^{-28}$ g.
19. Boltzmann constant, $k = 1.38066\text{x}10^{-23}$J/K
20. Electron charge, $q = 1.60218\text{x}10^{-19}$ Coulomb
21. Permittivity of free space, $\varepsilon_o = 8.85418\text{x}10^{-14}$ Fd/cm
22. Relative permittivity of silicon, $\varepsilon_r = 11.7$
23. Relative permittivity of silicon dioxide, $\varepsilon_{rOx} = 3.9$
24. 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.
25. Each part is worth [x] points, as given in the problem.
26. In each case, make the simplest realistic computation, noting the assumptions

A p+n junction with Na=1e18/cm^3 and Nd=5E15/cm^3 on the p+ side and and Nd=5E15/cm^3 on the n side is fabricated with a junction area Aj = 235E-8 cm^2. It is known that the charge neutral region width of the lightly doped side (at vd = 0) is 1 micron.

1. Find TAUn on the p-side

TAUmin = (45E-6 sec)/(1+7.7E-18*Nimp+4.5E-36*Nimp2), Nimp = 1e18 + 5e15
TAUn = 3.39E-06 sec

Answer 1[10]. ____________________

2. Find Dp on the n-side

Dp = Mup*Vt = Vt*((418.3/(1+(Ni/1.6E17)^0.7))+49.7), Ni = Na = 5e15
Dp = = Vt*((418.3/(1+(5e15/1.6E17)^0.7))+49.7)
Dp = 11.2 cm^2/sec

Answer 2[10]. ____________________

3. Evaluate the IS for this diode.

Assume "short diode", which is appropriate since Wcnr = 1 micron.
IS = q*ni^2*A*Dp/(Nd*Wcnr) = q*ni^2*235e-8*11.2/(5e15*1e-4)
IS = 9.67E-16 Amp

Answer3[10]. ____________________

4. Using the procedure of Massobrio and Antognetti, estimate IKF, the current at which the high level injection diode current is the same as the low level injection diode current.

IKFlli = q*ni^2*A*Dp/(Nd*Wcnr)exp(VKF/Vt) low-level injection at VKF
IKFhli = 2*q*ni*A*Dp/Wcnr*exp(VKF/(2*Vt)) high-level injection at VKF, M&A eqn. 1-14
equating IKFlli = IKFhli, and solving for VKF, then substituting into IKFlli,
VKF = 2*Vt*ln(2*Nd/ni) 0.711 V
IKF = IS*exp(2*ln(2*Nd/ni)) = 8.45E-04 A

Answer 4[10]. ____________________

5 [6]. Why does the high level injection current formula given in Massobio and Antognetti differ from that given in the lectures by a factor of 2?

In class, we neglected the majority carrier diffusion in the high level injection calculation.

6. Evaluate Vbi = VJ for this diode.

Vbi = Vt*ln((Na-Nd)*Nd/ni^2) = Vt*ln((1e18-5e15)*5e15/ni^2)
Vbi = 0.812 V

Answer 6[10]. ____________________

7. Evaluate CJO for this diode.

CJO = eo*erSi*A/W(0) = A*sqrt(eo*erSi*q*Nd/(2*Vbi))
CJO = 5.31288E-14 Fd

Answer 7[10]. ____________________

8. Evaluate the diffusion conductance at vd = vj = 650 mV for this diode (assume N = 1, and there is negligible recombination current).

gd = iD/(N*Vt) = IS*exp(0.650/Vt)/Vt
gd = 3.11E-03 A/V

Answer 8[10]. ____________________

9. Evaluate the diffusion capacitance at vd = vj = 650 mV for this diode (assume N = 1, and there is negligible recombination current).

Cd/gd = TAUtr = Wpcnr^/(2*Dp)   TAUtr =   4.45611E-10
Cd = Wpcnr^2*gd/(2*Dp)
Cd =   1.39E-12   Fd

Answer 9[10]. _____________________

10. A different diode has id = 100 microAmp at vd = 600 mV and id = 125.89 microAmp at vd = 606 mV. Find the effective ideality factor Neff for this diode.

d(ln(id))/dvd = (Neff*Vt)^-1
Neff = (d(ln(id))/dvd*Vt)^-1 = (v2-v1)/(ln(i2/i1)*Vt)
Neff = 1.008

Answer 10[14]. _____________________