

Test 01 - EE 5342 (print last name) \_\_\_\_\_ (print first name) \_\_\_\_\_.

Tuesday, February 19, 2002

**80 minutes allowed** (last four digits of your student #) \_\_\_\_\_ (e-mail if new) \_\_\_\_\_

Instructions:

1. Do your own work.
2. Use a legal copy of any text(s) AND a sheet of hand-written notes. You may NOT pass a book or note sheet to another student. You MAY use a copy of class notes. Do not use previously solved problems. Hint: the fewer resources you use, the better you will do. Probably all required resources are on this cover sheet.
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.
7. Show all calculations, making numerical substitutions and giving numerical results where possible.
8. Write answers in space given.
9. Unless stated otherwise,  
 $T = 300\text{K}$ ,  
 $V_t = 25.852\text{ mV}$ ,  
 $\epsilon_o = 8.85\text{E-14 Fd/cm}$ ,  
 $q = 1.602\text{E-19 Coul}$ .
10. Unless otherwise stated, the material is silicon with  
 $n_i = 1.07\text{E}10\text{ cm}^{-3}$ ,  
 $N_c = 2.84\text{E}19\text{ cm}^{-3}$ ,  
 $N_v = 3.08\text{E}19\text{ cm}^{-3}$ ,  
 $q\chi_{\text{Si}} = 4.05\text{ eV}$ ,  
 $E_{g,\text{Si}} = 1.125\text{ eV}$ , and  
 $\epsilon_{\text{Si}} = 11.7$ .
11. For holes in silicon, assume  
 $\mu_p = \{418.3 \div [1 + (N_i \div 1.6\text{E}17)^{0.7}]\} + 49.7$ , in  $\text{cm}^2/\text{V-sec}$   
(where  $N_i$  = the total impurity concentration in n- or p-type material whether compensated or not).
12. For electrons in silicon, assume  
 $\mu_n = \{1268 \div [1 + (N_i \div 1.3\text{E}17)^{0.91}]\} + 92$ , in  $\text{cm}^2/\text{V-sec}$   
(where  $N_i$  = the total impurity concentration in n- or p-type material whether compensated or not)
13. For minority carriers in silicon, use the relationship  
 $\tau_{\text{min}} = [45\text{E-6 sec}] \div [1 + 7.7\text{E-18} * N_i + 4.5\text{E-36} * N_i^2]$   
(where  $N_i$  = the total impurity concentration) for minority carrier lifetime (either electrons or holes).
14. For the work function of n+ poly silicon, use  
 $\phi_{n+} = \chi_{\text{Si}} = 4.05\text{ V}$ ,  
and for the work function of p+ poly silicon, use  
 $\phi_{p+} = \chi_{\text{Si}} + E_{g,\text{Si}}/q = 5.175\text{ V}$ .
15. Metal gate work functions should be assumed to be (gold)  $\phi_{\text{Au}} = 4.75\text{ V}$ , (aluminum)  $\phi_{\text{Al}} = 4.1\text{V}$ .
16.  $\text{SiO}_2$ , the electron affinity is  $\chi_{\text{SiO}_2} = 0.95\text{ V}$ , the relative permittivity is  $\epsilon_{\text{SiO}_2} = 3.9$ .

1. A p+n diode is to be formed on a piece of Si material with  $N_d = 3.000E+16 \text{ cm}^{-3}$  which is  $3.00E-04 \text{ cm} = 3 \text{ microns} = 3 \mu\text{m}$  thick. For the lightly doped side, find the equilibrium electron and hole concentrations, the electron and hole mobilities, the electron and hole diffusion coefficients, the minority carrier lifetime, the minority carrier diffusion length, Note, the anode is made by adding  $2.000E+18 \text{ cm}^{-3}$  acceptor ions to the n-type silicon to a depth of 1 micron =  $1.000E-04 \text{ cm}$ .

a. [4]  $n = \underline{3.000E+16 \text{ cm}^{-3}}$ ,

b. [4]  $p = \underline{3.816E+03 \text{ cm}^{-3}}$ ,

c. [4]  $\mu_n = \underline{1096 \text{ cm}^2/\text{V-sec}}$ ,

d. [4]  $\mu_p = \underline{369 \text{ cm}^2/\text{V-sec}}$ ,

e. [4]  $D_n = \underline{28.3 \text{ cm}^2/\text{sec}}$ ,

f. [4]  $D_p = \underline{9.5 \text{ cm}^2/\text{sec}}$ ,

g. [4]  $\tau_{\text{min}} = \underline{3.644E-05 \text{ sec}}$ ,

h. [4]  $L_{\text{min}} = \underline{1.864E-02 \text{ cm}}$ ,

2. Calculate the built-in voltage, the total depletion width, the depletion width on the n-side, the charge-neutral width in the cathode and the transit time in the cathode for this diode for  $v_a=0$ . Remember, the charge-neutral width is the width of the region minus the depletion width in the region.

a. [4]  $V_{bi} = \underline{0.876 \text{ V}}$ ,

b. [4]  $W = \underline{1.928\text{E-}05 \text{ cm}}$ ,

c. [4]  $x_n = \underline{1.899\text{E-}05 \text{ cm}}$ ,

d. [4]  $W_{n,CNR} = x_{nc} - x_n = \underline{1.810\text{E-}04 \text{ cm}}$ ,

e. [4] and  $\tau_{TR} = \underline{1.717\text{E-}09 \text{ sec}}$ ,

f. [4] Is this a long, or short diode. Why?

$x/L$   
 $9.708\text{E-}03$       short

3. Calculate the resistivity of the cathode material.

[4]  $\rho_{\text{cathode}} = \underline{1.90\text{E-}01 \text{ ohm-cm}}$ .

4. Calculate the resistivity of the anode material.

$$[4] \rho_{\text{anode}} = \underline{1.68\text{E-}02 \text{ ohm-cm}}.$$

5. Estimate the SPICE parameter for the saturation current density,  $J_S \equiv I_S/\text{Area}$ .

$$[8] J_S = \underline{3.268\text{E-}11 \text{ A/cm}^2}.$$

6. Calculate the zero-voltage capacitance per unit area, and  $v_D = v_a = -3 \text{ V}$  for this diode.

$$[4] C'_j(v_a=0) = C'_{\text{depl}}(v_a=0) = \underline{5.371\text{E-}08 \text{ Fd/cm}^2},$$

$$[4] C'_j(v_a = -3) = C'_{\text{depl}}(v_a = -3) = \underline{2.553\text{E-}08 \text{ Fd/cm}^2}.$$

7. At 300K, a certain diode is known to have negligible recombination current at a forward bias of 650 mV, where  $i_D = 5 \text{ mA}$ . A plot of  $\log(i_D)$  vs.  $v_D$  at  $v_D = 650 \text{ mV}$  has a slope of 1 decade/70 mV. What is the ideality factor,  $\eta = NF$ , and the saturation current,  $I_S$ , for this diode?

$$N = (70\text{mA/decade})/(59.526\text{ma/decade})$$

$$[8] \eta = NF = \underline{1.18}.$$

$$\ln(I_S) = \ln(i_D) - v_D/(N \cdot V_t), \text{ so } I_S = i_D \cdot \exp(-v_D/(N \cdot V_t))$$

$$[8] I_S = \underline{2.59014\text{E-}12 \text{ A}}.$$

8. At 300K, a similar diode is known to have a recombination current (ideality factor of  $NR = 2$ ) of 5% of the injection current at a forward bias of 650 mV, where  $i_D = 5 \text{ mA}$ . A plot of  $\log(i_D)$  vs.  $v_D$  at  $v_D = 650 \text{ mV}$  has a slope of 1 decade/70 mV. What is the ideality factor,  $\eta = NF$ , for this diode?

$$d[\log(i_D)]/dv_D = \log(e) \cdot d[\ln(i_D)]/dv_D = \log(e) \cdot [(I_S/NFV_t) \cdot e^{v_D/NV_t} + (ISE/2V_t) \cdot e^{v_D/2V_t}] / [I_S(e^{v_D/NV_t} - 1) + ISE(e^{v_D/2V_t} - 1)],$$

$$i_D = I_S \cdot (e^{v_D/NV_t} - 1) + ISE \cdot (e^{v_D/2V_t} - 1) \approx I_S \cdot e^{v_D/NV_t} + ISE \cdot e^{v_D/2V_t}, \text{ and } I_S \cdot e^{v_D/NV_t} = 0.95 \cdot i_D, \text{ and } ISE \cdot e^{v_D/2V_t} = 0.05 \cdot i_D,$$

$$\text{so } NF^{-1} = [1\text{decade}/70\text{mV} \cdot 5\text{mA} - 0.5\text{decade}/59.526\text{mV} \cdot 0.05 \cdot 5\text{mA}] / [0.95 \cdot 5\text{mA} \cdot 1\text{decade}/59.526\text{mV}].$$

$$[8] \eta = NF = \underline{1.151}.$$