Test 1 - EE 5340/4329 (print last name)________________ (print first name) Key

Thursday, September 28, 2000

80 minutes allowed (student #) ______-______-______ (e-mail)______________

Instructions: Do your own work. Open book (including class handouts), calculator allowed, no notes. Each part is worth [x] points. **Explicitly state definitions and assumptions that you use. Where possible, calculate parameters rather than read them from a graph.** Do all work on this paper. Show all calculations, making numerical substitutions and giving numerical results where possible. Write answers in space given. Unless stated otherwise, T = 300K and V_t = 25.852 mV.

1. A sample of semiconductor material has a uniform impurity distribution of 7E15/cm^3 phosphorous and 3E16/cm^3 boron. First, solve for the net donor concentration.

$N_D = 7e15 \quad N_A = 3e16$

$n = N_D - N_A = 7e15 - 3e16 = -2.3e16\ cm^{-3}$

a. [6] N = $-2.3e16\ cm^{-3}$. Next, determine the value to use for the intrinsic carrier concentration and document your reasoning.

$n_i = 1.07 \times 10^{10}\ cm^{-3}$ for Si at 300 K

from Table 2.3 of text book

b. [6] n_i = $1.07 \times 10^{10}\ cm^{-3}$. Next, determine the majority carrier type.

$N = -2.3e16 \Rightarrow$ P type

c. [6] The majority carriers are [electrons] (circle correct answer) [holes]. Next, determine the hole concentration.

d. [6] p_o = $2.3e16\ cm^{-3}$

1.(continued) Next, determine the electron concentration.

$$n = \frac{n_i^2}{P} = \frac{(1.07\times10^{10})^2}{2.3e16} = 4.978\times10^3$$

e. [6] n_o = $4978\ cm^{-3}$.

2. The following information is all that is known about a particular semiconductor: At T = 300 K, E_g = 1.35 eV, N_c = 4E18 cm^{-3}, and N_v = 2E18 cm^{-3}. Solve for the intrinsic carrier concentration.

$$n_i = \left[N_c N_v \exp\left(-\frac{E_g}{KT}\right)\right]^{\frac{1}{2}} = \left[4\times10^{18}\times2\times10^{18}\exp\left(-\frac{1.35}{0.025852}\right)\right]^{\frac{1}{2}}$$
$$= 1.294\times10^{7}$$

a. [6] n_i(300K) = $1.294\times10^{7}\ cm^{-3}$. Next, make the best possible numerical estimate of n_i(250K).

$$N_{c,v} = 2.5\times10^{19}\left(\frac{m^*_{n,p}}{m_0}\right)^{3/2}\left(\frac{T}{300}\right)^{3/2}$$ assume $\frac{m^*_{n,p}}{m_0}$ and E_g are constant

$$N_c(250) = 4e18\times\left(\frac{250}{300}\right)^{3/2} = 3.04\times10^{18}$$ $$N_v(250) = 2e18\times\left(\frac{250}{300}\right)^{3/2} = 1.52\times10^{18}$$

$$n_i = \left[3.04\times10^{18}\times1.52\times10^{18}\times\exp\left(\frac{-1.35}{0.025852\times\frac{5}{6}}\right)\right]^{\frac{1}{2}}$$

$$= 5.308\times10^{4}/cm^3$$

b. [6] n_i(250K) = $5.308\times10^{4}\ cm^{-3}$.

3. Calculate the majority carrier ~~hole~~ electron mobility at 300K for silicon with N_d = 5E16 cm^{-3}.

Pierret Model $$\mu_n = \mu_{min} + \frac{\mu_0}{1+\left(\frac{N}{N_{ref}}\right)^{\alpha}} = 92 + \frac{1268}{1+\left(\frac{5\times10^{16}}{1.3\times10^{17}}\right)^{0.91}}$$

$$= 985\ cm^2/V\text{-}s$$

a. [6] μ_n = $985\ cm^2/V\text{-}s$. Next, calculate the resistivity of this material.

$$\rho = \frac{1}{q\mu_n n} = \frac{1}{1.6\times10^{-19}\times985\times5\times10^{16}} = 0.127\ \text{ohm-cm}$$

b. [6] ρ = 0.127 ohm - cm.

3.(continued)Next, calculate the position of the Fermi level of this material relative to the conduction band edge.

$$E_c - E_{Fn} = 0.025852 \ln \frac{N_c}{n} \qquad N_c = 3.22\times10^{19}/cm^3$$

$$= 0.025852 \ln\left(\frac{3.22\times10^{19}}{5\times10^{16}}\right) = 0.167\ eV$$

c. [6] $E_f - E_c$ = $-0.167\ eV$.

4. At 100K, calculate E_g for silicon.

$$(2.72) \qquad E_g(T) = 1.17 - 4.73\times10^{-4}\frac{T^2}{(T+636)}$$

$$E_g(100) = 1.17 - 4.73\times10^{-4}\times\frac{(100)^2}{736} = 1.1699$$

a. [6] E_g(100K) = 1.163 eV. **Next, calculate N_c for silicon at 100K.**

$$(2.66) \qquad N_c = 2.5\times10^{19}\left(\frac{m_n^*}{m_0}\right)^{3/2}\left(\frac{T}{300}\right)^{3/2} \quad \text{from Table 2.3}, \ \frac{m_n^*}{m_0} = 1.09$$

$$N_c = 2.5\times10^{19}\times(1.09)^{3/2}\left(\frac{100}{300}\right)^{3/2} = 5.475\times10^{18}$$

b. [6] N_c(100K) = $5.475\times10^{18}\ cm^{-3}$.

5. A p-n junction abrupt junction diode has N_a = 5E14 cm^{-3} and N_d = 6E17 cm^{-3}. Solve for V_{bi}.

$$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.025852 \ln\left(\frac{5\times10^{14}\times6\times10^{17}}{(1\times10^{10})^2}\right)$$

$$= 0.742$$

a. [6] V_{bi} = 0.742 V. **Next, solve for the junction width at V_a = -7.0 Volts**

$$W = \sqrt{\frac{2\times11.8\times8.85\times10^{-14}\times(0.742+7)}{1.6\times10^{-19}\times4.996\times10^{14}}} \qquad N_D \gg N_A \quad N_{eff} \simeq N_A = 5\times10^{14}$$

$$= 4.496\times10^{-4}\ cm$$

b. [6] W = 4.496 um.

5.(continued) Next solve for the transition or Debye length on the p side of the diode.

$$L_{D.p} = \sqrt{\frac{\varepsilon V_t}{q N_a}} = \sqrt{\frac{11.8 \times 8.85 \times 10^{-14} \times 0.025852}{1.6 \times 10^{-19} \times 5 \times 10^{14}}} = 1.84 \times 10^{-5}\ cm$$

c. [6] L_D = $0.184\ \mu m$. Next, solve for the magnitude of the maximum electric field in the depletion region when V_a = -7 V.

$$E_{max} = \sqrt{\frac{2q(V_{bi} - V_a) N_{eff}}{\varepsilon}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times (7.742) \times 5 \times 10^{14}}{11.8 \times 8.85 \times 10^{-14}}}$$

$$= 34.4\ kV/cm$$

d. [6] E_{max} = $34.4\ kV/cm$. Next, solve for the junction capacitance when V_a = 0 V.

$$C_j' = C_{j0}' = \sqrt{\frac{\varepsilon q N_{eff}}{2 V_{bi}}} = \sqrt{\frac{11.8 \times 8.85 \times 10^{-14} \times 5 \times 10^{14} \times 1.6 \times 10^{-19}}{2 \times 0.742}}$$

e. [6] C_j' = $7.5 \times 10^{-9}\ Fd/cm^2$.