KEY

Test 1 - EE 5340/001 (print last name) ___________________________ (print first name) ______________________

Tuesday, September 22, 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, yEx = $y \times 10^x$.
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/7.70E-18 + (N_i/4.71E17)^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 boron doped (concentration of 6.7E15/cm^3) wafer is the material for this problem.
a. Calculate the majority carrier mobility of this material.

Ni = 6.70E+15 Boron

480.4 = MUp = (470.5 /(1+(Ni/2.23E17)^0.719))+44.9

a. [7] $\mu_{\text{majority carriers}}$ = ____________________cm^2/V-sec.
b. Next, calculate the minority carrier concentration and type.

po*no = ni^2, ni = 1.45E+10 /cm^3
po = Na = 6.70E15
no = ni^2/Na
no = 3.14E+04 /cm^3
The type of carrier is electron

b. [6] The minority carrier concentration = __________ cm^{-3}. [2] The minority carrier type is ____________.
c. Calculate the majority carrier contribution to the resistivity of the material.

RHOp = 1/(po*q*Mup), q = 1.60E-19 Coulomb
RHOp = 1.94 Ohm-cm

c. [6] The majority carrier contribution to the resistivity is ________________________ Ohm-cm.
d. Calculate an estimate of the minority carrier contribution to the resistivity of the material.

Assume the minority electron mobility can be
modeled as Phosphorous where Ni = Na
Ni = 6.7E+15 as if it were Phos.
1292.5 = Mun = (1414/(1+(Ni/9.20E16)^0.711))+68.5
RHOn = 1/(no*q*Mun), q = 1.60E-19 Coulomb
RHOp = 1.54E+11 Ohm-cm
Note: Since both components are in parallel, this resistance is inconsequential.

d. [8] The minority carrier contribution to the resistivity is ________________________ Ohm-cm.

2. A wafer of silicon has boron concentration 6E15/cm^3. A p-n step junction has this concentration on one side and a constant concentration of N_d = 8E17/cm^3 on the other side. Calculate the built-in voltage, $V_{bi} = \phi_i$, for this junction.

Na =	6.00E+15	/cm^3			
Nd =	8.00E+17	/cm^3	ni =	1.45E+10	/cm^3
Vbi =	Vt*ln(Na*Nd/ni^2)		Vt =	25.843	mV
Vbi =	795	mV			

a. [7] V_{bi} = ____________________ V.

3. A Silicon wafer has a uniform impurity distribution of 5E16 cm^{-3} arsenic atoms.

a. Calculate $E_c - E_f$.

Ec - Ef =	kT*ln(Nc/Nd)		kT =	25.843	meV
=	164	meV	Nc =	2.80E+19	/cm^3
			Nd =	5.00E+16	/cm^3

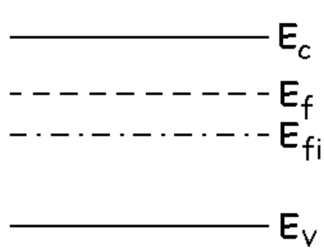
a. [6] $E_c - E_f$ = ____________________.

b. Next, calculate E_f - E_i.

Ec - Ef =	kT*ln(Nd/ni)		kT =	25.843	meV
=	389	meV	ni =	1.45E+10	/cm^3
			Nd =	5.00E+16	/cm^3

b. [6] Ef - Ei = ____________________.

c. [6] Next, draw the energy band diagram showing E_c, E_f, E_i, E_v for this material



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4. An ideal Schottky diode is fabricated with gold on silicon doped with a concentration of 2E15 cm^{-3} phosphorous atoms.

a. What is the Fermi potential, φ_n, for the phosphorous doped silicon?

PHIn =	Vt*ln(Nd/ni)			Vt =	25.843	mV
=	306	mV		ni =	1.45E+10	/cm^3
				Nd =	2.00E+15	/cm^3

a. [6] φ_n = _______________ V.

b. What is the total band bending, φ_i, in the silicon at the metal-semiconductor interface for $V_a = 0$ V?

Ec-Ef	=	Vt*ln(Nc/Nd)		Nc =	2.80E+19	/cm^3
	=	247 meV				
PHI,i	=	PHI,M - (CHI,Si + (Ec-Ef))/q		PHI,M =	4.75	V
PHI,i	=	453 mV		CHI,Si =	4.05	V

b. [6] φ_i = _______________ V.

c. What is the depletion region depth in the silicon at the metal-semiconductor interface for $V_a = 0$ V?

xd =	sqrt(2*eo*ersi*(PHI,I - Va)/(q*Nd))		eo =	8.854E-14	Fd/cm
xd =	0.541 microns		er,Si =	11.7	
			q =	1.602E-19	Coul
			Nd =	2.00E+15	/cm^3

c. [7] x_d = _______________ µm.

d. What is the capacitance (in Fd/cm^2) when the metal contact is -2 V relative to the semiconductor contact?

xd =	sqrt(2*eo*ersi*(PHI,I - Va)/(q*Nd))		eo =	8.854E-14	Fd/cm
xd =	1.26 microns		er,Si =	11.7	
C'j =	eo*ersi/xd		q =	1.602E-19	Coul
C'j =	8.22E-10 Fd/cm^2		Nd =	2.00E+15	/cm^3

d. [6] C'_j = _______________ Fd/cm^2

5. [7] Using the numerical data on given in Table 1.3, what is the temperature, T, where $n_{i,Ge} = 8\times10^3\, n_{i,Si}$?

ni(T) = sqrt((Nc(T)*Nv(T)*exp(-Eg(T)/kT)))
Nc(T) = Nc(300)*(T/300)^3/2, Nv(T) = Nv(T)*(T/300)^3/2, Eg(T) = Eg(300)*(1 + (dEg/dT)*(T-300)
sqrt((NcGe(T)*NvGe(T)*EXP(-EgGe(T)/kT))) = 8E3*sqrt((NcSi(T)*NvSi(T)*EXP(-EgSi(T)/kT)))
sqrt(NcGe(300)*NvGe(300)*(T/300)^3*exp(-(EgGe(300) + (dEgGe/dT)*(T-300))/kT))
= 8E3*sqrt(NcSi(300)*NvSi(300)*(T/300)^3*exp(-(EgSi(300) + (dEgSi/dT)*(T-300))/kT))((EgSi(300) + (dEgSi/dT)*(T-300)) -(EgGe(300) + (dEgGe/dT)*(T-300)))/kT)
=ln(8E3*sqrt(NcSi(300*NvSi(300)/(NcGe(300*NvG3(300))))

$$n_i(T) = \sqrt{N_C(T)N_V(T)\exp\left(\frac{-E_G(T)}{kT}\right)}, \text{find T for which } n_{i,GE}(T) = 8\times10^3 n_{i,Si}(T)$$

$$N_C(T) = N_C(300)\left(\frac{T}{300}\right)^{3/2},\ N_V(T) = N_V(300)\left(\frac{T}{300}\right)^{3/2},\ E_G(T) = E_G(300) + \left.\frac{\partial E_G}{\partial T}\right|_{300}(T-300)$$

6. A resistor is to be made in a region of semiconductor material of uniform thickness, t = 1μm, and boron doping concentration N_a = 2E16 cm^{-3} which is imbedded in a lightly doped n-type wafer. The current will flow along the length, L. The width of the resistor is W, so the cross-sectional area, A = W×t.
a. What L/W ratio is required for this resistor to have a resistance of 100 Ohms?

Ni =	**2.00E+16**	**Boron q =**	**1.60E-19**	**Coulomb**	**t =**	**1.00E-04**	**cm**

444.8 = MUp = (470.5 /(1+(Ni/2.23E17)^0.719))+44.9
RHOp = 1/(po*q*MUp) = 0.702 Ohm-cm
R = L/W*RHOp/t = 100 Ohm
L/W = R*t/RHOp = 1.43E-02, *an impractical value*

a. [7] L/W = ____________________.

b. When the applied voltage is 5 Volts, what is the W value for this 100 Ohm resistor to have a power density of 1μW/cm^2 at 5 Volts?

P/A = P' = V^2/(R*W*L), P' = P/(W*L) = 1.00E-06 W/cm^2
From above, W = L/1.43E-2
So, W = sqrt(V^2*1.43E-2/(R*P')) = sqrt(5^2*1.43E-2/(100*1e-6))
W = 59.7 cm, *an impractical value*
The area of an IC resistor is usually W*L. The area used in the resistance calculation is W*T. If W*T was used instead of W*L, the approach was accepted.

b. [7] W = ______________________ μm.