Indian Institute of Technology

Semiconductor Devices — **course no. EC 21107**
End-Semester(2009-10) Autumn — **Full marks: 100**
Time: 3 Hrs.

(Attempt all)
(For specified physical properties do not use attached table)

1. a) An Si crystal is to be pulled from the melt and doped arsenic (k_d=0.3). If the Si weighs 1 kg, how many grams of arsenic should be introduced to achieve 10^{15} cm^{-3} doping during the initial growth? Atomic weight of As 74.9, density of Si 2.33 g/cm^3 5
   b) The ionic radii of Na^+ (atomic weight 23) and Cl^- (atomic weight 35.5) are 1.0 and 1.8 Å, respectively. Treating the ions as hard sphere, calculate the density of NaCl. Compare this with the measured density of 2.17 g/cm^3. 5
2. We define a potential well having energies V as a function of position x, as follows: V= ∞ for x= -0.5 nm to 0; V= 0 eV for x= 0 to 5 nm; V= 10 eV for x= 5 to 6 nm, and V= 0 for x> 6 nm and x<- 0.5 nm. We put an electron with energy 7 eV in the region x, between 0 and 5 nm. What is the probability of finding the electron at x< 0 nm? Is there any probability of finding the electron at x>6 nm zero or non zero? What is the probability for x>6 nm if the electron was described by classical mechanics and not quantum mechanics? 10
3. a) A Si sample is doped with 10^{17} boron atoms/cm^3. What is the electron concentration n_0 at 300 K? What is the resistivity? n_i of Si 1.5 x $10^{10}/cm^3$ μ_p=250cm^2/v.s 5
   b) A Ge sample is doped with 3 x 10^{13} Sb atoms/cm^3. Using the requirements of space charge neutrality, calculate the electron concentration n_0 at 300 K. 5
4. For a 2-cm-long doped Si bar (N_d= 10^{16} cm^{-3}) with a cross sectional area = 0.05 cm^2, what is the current if we apply 10 V across it? If we generate 10^{20} electron hole pairs per second per cm^3 uniformly in the bar and the lifetime τ_n= τ_p= 10^{-4} s, what is the new current? Assume the low-level α_r doesn't change for high-level injection. If the voltage is then increased to 100,000 V, what is the new current? Assume μ_p= 500 cm^2/V-s, μ_n= 1070 cm^2/V-s. n_0= 10^{15} / cm^3 10
5. a) A Si p^+-n junction 10^{-2} cm^2 in area has N_d =10^{15} cm^{-3} doping on the n side. Calculate the junction capacitance with a reverse bias of 10 V. 5
   b) An abrupt p^+-n junction is formed in Si with a donor doping of N_d = 10^{15} cm^{-3} what is the depletion region thickness W just prior to avalanche breakdown? V_{br}=300 V 5
6. You have a symmetric p-n silicon junction (N_a= N_d= 10^{17} cm^{-3}). If the peak electric field in the junction at breakdown is 5 x 10^5 V/cm, what is the reverse breakdown voltage in this junction? 10
7. An Al-gate p-channel MOS transistor is made on an n-type Si- substrate with N_d= 5 x 10^{17} cm^{-3}. The SiO_2 thickness is 100 Å in the gate region, and the effective charge interface charge is Q_i= 5 x 10^{10} qC/cm^2. Find W_m, V_{FB} and V_T. Sketch the

C-V curve for this device and give important numbers for the scale. $\varepsilon_i = 3.9\ \varepsilon_s = 11.8$, $n_i = 1.5 \times 10^{10}\ /cm^3$ 10

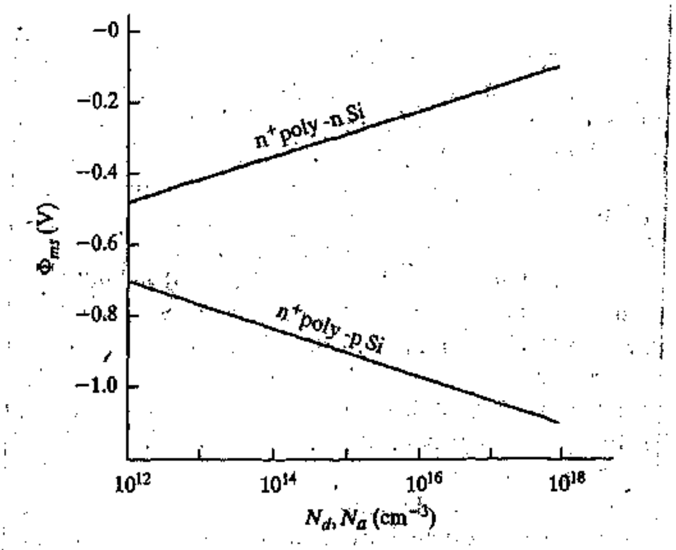
8. Calculate the V_T of a Si n-channel MOSFET for a gate-to-substrate workfunction difference $\Phi_{ms} = -1.5$ eV, gate oxide thickness = 100 Å, $N_A = 10^{18}\ cm^{-3}$, and fixed oxide charge of $5 \times 10^{10}\ qC/cm^2$, for a substrate bias of -2.5 V. At V_T, what are the electron and hole concentration at the oxide-Si interface and deep in the substrate? Sketch a labeled band diagram normal to the surface at V_T, showing the Fermi potential. assume $(kT/q) = 0.026$, $Q_D = 1.071 \times 10^{-6}$ C 10
9. For a p-n-p BJT with $N_E > N_B > N_C$, show the dominant current components, with proper arrows, for directions in the normal actine mode. If $I_{Ep} = 10$ mA, $I_{En} = 100\ \mu A$, $I_{Cp} = 9.8$ mA, and $I_{Cn} = 1\ \mu A$, calculate the base transport factor, emitter injection efficiency, common-base current gain,common-emitter current gain, and I_{CBO}. If the minority stored base charge is 4.9×10^{-11} C, calculate the base transit time and lifetime. 10
10. A Si p-n-p BJT has the following parameters at room temperatures at room temperature.

Emitter: $N_a = 5 \times 10^{18}\ cm^{-3}$, $\tau_n = 100$ ps , $\mu_n = 150\ cm^2/V\text{-}s$ $\mu_p = 100\ cm^2/V\text{-}s$ Base width $W_b = 0.2\ \mu m$ Area= $10^{-4}\ cm^2$,

Base: $N_d = 10^{16}$, $\tau_p = 2500$ ps, $\mu_n = 1500$, $\mu_p = 400$

Collector: $N_a = 10^{15}$, $\tau_n = 2\ \mu s$, $\mu_n = 1500$, $\mu_p = 450$

Calculate the β of the transistor from B and γ, and using the charge control model. 10



Properties of Semiconductor Materials

		E_g (eV)	μ_n (cm^2/V-s)	μ_p (cm^2/V-s)	m^*_n/m_0 (m_l, m_t)	m^*_p/m_0 (m_{lh}, m_{hh})	a (Å)	ϵ_r	Density (g/cm^3)	Melting point (°C)
Si	(*i*/D)	1.11	1350	480	0.98, 0.19	0.16, 0.49	5.43	11.8	2.33	1415
Ge	(*i*/D)	0.67	3900	1900	1.64, 0.082	0.04, 0.28	5.65	16	5.32	936
SiC (α)	(*i*/W)	2.86	500	—	0.6	1.0	3.08	10.2	3.21	2830
AlP	(*i*/Z)	2.45	80	—	—	0.2, 0.63	5.46	9.8	2.40	2000
AlAs	(*i*/Z)	2.16	1200	420	2.0	0.15, 0.76	5.66	10.9	3.60	1740
AlSb	(*i*/Z)	1.6	200	300	0.12	0.98	6.14	11	4.26	1080
GaP	(*i*/Z)	2.26	300	150	1.12, 0.22	0.14, 0.79	5.45	11.1	4.13	1467
GaAs	(*d*/Z)	1.43	8500	400	0.067	0.074, 0.50	5.65	13.2	5.31	1238
GaN	(*d*/Z, W)	3.4	380	—	0.19	0.60	4.5	12.2	6.1	2530
GaSb	(*d*/Z)	0.7	5000	1000	0.042	0.06, 0.23	6.09	15.7	5.61	712
InP	(*d*/Z)	1.35	4000	100	0.077	0.089, 0.85	5.87	12.4	4.79	1070
InAs	(*d*/Z)	0.36	22600	200	0.023	0.025, 0.41	6.06	14.6	5.67	943
InSb	(*d*/Z)	0.18	10^5	1700	0.014	0.015, 0.40	6.48	17.7	5.78	525
ZnS	(*d*/Z, W)	3.6	180	10	0.28	—	5.409	8.9	4.09	1650*
ZnSe	(*d*/Z)	2.7	600	28	0.14	0.60	5.671	9.2	5.65	1100*
ZnTe	(*d*/Z)	2.25	530	100	0.18	0.65	6.101	10.4	5.51	1238*
CdS	(*d*/W, Z)	2.42	250	15	0.21	0.80	4.137	8.9	4.82	1475*
CdSe	(*d*/W)	1.73	800	—	0.13	0.45	4.30	10.2	5.81	1258
CdTe	(*d*/Z)	1.58	1050	100	0.10	0.37	6.482	10.2	6.20	1098
PbS	(*i*/H)	0.37	575	200	0.22	0.29	5.936	17.0	7.6	1119
PbSe	(*i*/H)	0.27	1500	1500	—	—	6.147	23.6	8.73	1081
PbTe	(*i*/H)	0.29	6000	4000	0.17	0.20	6.452	30	8.16	925

All values at 300 K. *Vaporizes

Physical Constants and Conversion Factors[1]

Avogadro's number	$N_A = 6.02 \times 10^{23}$ molecules/mole
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ J/K
	$= 8.62 \times 10^{-5}$ eV/K
Electronic charge (magnitude)	$q = 1.60 \times 10^{-19}$ C
Electronic rest mass	$m_0 = 9.11 \times 10^{-31}$ kg
Permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-14}$ F/cm
	$= 8.85 \times 10^{-12}$ F/m
Planck's constant	$h = 6.63 \times 10^{-34}$ J-s
	$= 4.14 \times 10^{-15}$ eV-s
Room temperature value of kT	$kT = 0.0259$ eV
Speed of light	$c = 2.998 \times 10^{10}$ cm/s

	Prefixes:		
1 Å (angstrom) $= 10^{-8}$ cm	milli-,	m-	$= 10^{-3}$
1 μm (micron) $= 10^{-4}$ cm	micro-,	μ-	$= 10^{-6}$
1 nm $= 10$ Å $= 10^{-7}$ cm	nano-,	n-	$= 10^{-9}$
2.54 cm = 1 in.	pico-,	p-	$= 10^{-12}$
1 eV $= 1.6 \times 10^{-19}$ J	kilo-,	k-	$= 10^{3}$
	mega-,	M-	$= 10^{6}$
	giga-,	G-	$= 10^{9}$

A wavelength λ of 1 μm corresponds to a photon energy of 1.24 eV.