INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Date ....21.... FN / AN Time : 2 / 3 Hrs. Full Marks ..100.. No. of Students ..94..

Autumn / Spring Semester, ... Deptt. ....E & ECE.... Sub. No. ....EC 21007....

..2nd.. Yr. B.Tech. (H) / B.Arch. (H) / M.Sc. Sub. Name ....Semiconductor Devices....

Instruction ....

1.

A) Calculate the first three energy levels of an electron in an infinite potential well of width 5 A and draw the wave functions in these energy levels. 4+2

B) Can an electron have a negative effective mass? Explain. 3

C) Calculate the volume density of Si atoms (number of atoms/cm^3). Given that the lattice constant of Si is 5.43A. Also calculate the areal density of atoms on (110) plane. 3+3

2.

A) Determine the induced electric field in thermal equilibrium (T=300 K) in a linearly doped semiconductor where donor concentration is given by $N_D = 10^{16} - 10^{19}x$ cm^{-3} for $0 \le x \le 1$ μm (x is in cm). Draw the band diagram and show the induced electric field due to non uniform doping. 6+2

B) Why Si doped with 10^{14} / cm^3 Sb is an n-type semiconductor but similarly doped Ge is not? Prove that minimum conductivity of a semiconductor sample occurs when, $n_o = n_i\sqrt{\mu_p/\mu_n}$. 3+5

C) In an n-type Silicon doped with N_D=1E16 cm^{-3}, plot carrier concentration vs. temperature graph for temperature range of 100-1000K. Also plot the variation of Fermi-level with temperature for same temperature range. 2+2

3.

A) Assume that a photo conductor in the shape of a bar of length L and area A has a constant voltage V applied and it is illuminated such that g_{op} EHP/ cm^3 are generated uniformly throughout. If $\mu_n >> \mu_p$, then we can assume that optically induced change in current (ΔI) is dominated by the mobility (μ_n) and life-time (τ_n) of electrons. Show that $\Delta I = q A L g_{op} \tau_n / \tau_t$ for this photo conductor, where τ_t is the transit time of electrons drifting down the length of the bar. 7

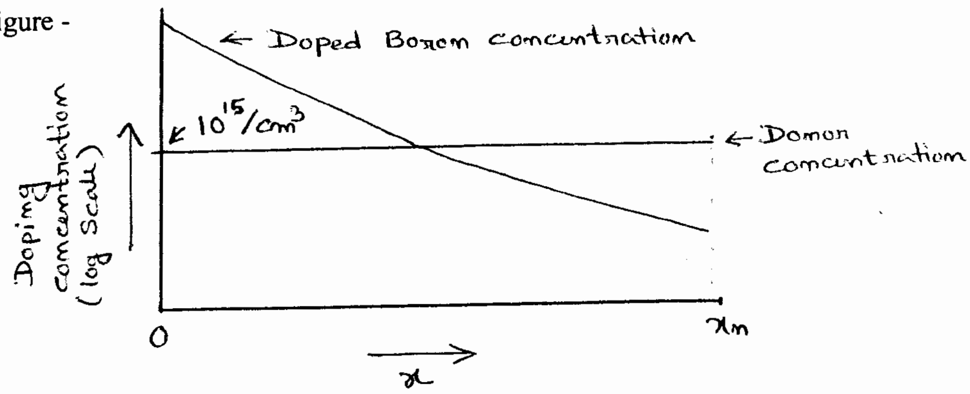
B) What is Ambipolar carrier transport and surface recombination velocity? A sample is doped with donors such that n_o=Gx for $n_o >> n_i$, where G is a constant. Find the built-in electric field ε(x). (2+2)+4

4.

A) A Silicon p-n junction has N_A=1E18 and N_D=5E15 cm^{-3}. Draw the band diagram. Find Fermi energy level in each side and the contact potential (V_o) at T=300K. Intrinsic concentration of Si is 1.5E10 cm^{-3}. 2+2+2

B) Consider a Si n^+-p junction with long p-region has the following properties, $N_A=10^{16}$ cm^{-3}, D_P =13 cm^2/s, μn =1000 cm^2/V-s, τ_n = 2 μs, ni=10^{10} cm^{-3}. If a forward bias voltage of 0.7 V is applied to the junction at 300 K, then what is the electric field in the p-region far from the junction? 8

C) In uniformly doped semiconductor p-n junction, how junction capacitance is related with the applied voltage? And for linearly graded junction what will be the relation? Where these properties can be used? Draw the net doping concentration if a uniformly doped n-type ($N_D=10^{15}/cm^3$) semiconductor is doped with boron as like in the figure - 1+1+2+2



5.

A) Calculate the V_T of a Si-MOS transistor for a n^+- polysilicon gate with silicon dioxide which is grown by PECVD for 10 min and growth rate is 5 A/min, N_D=1E18 cm^{-3} and fixed charge of 2E10q C/cm^2. Is it an enhancement or depletion mode device? What B dose is required to change the V_T to 0V? Assume a shallow B implant. 8

B) For an n-channel Si JFET, p^+ regions are doped with N_A=1E18 cm^{-3} and channel with N_D=1E16 cm^{-3}. If the channel half width a is 1μm, compare V_p with Vo. Find $V_{D\,Sat}$ if V_G= -3 V. (where all symbols indicates their usual meanings) 7

6.

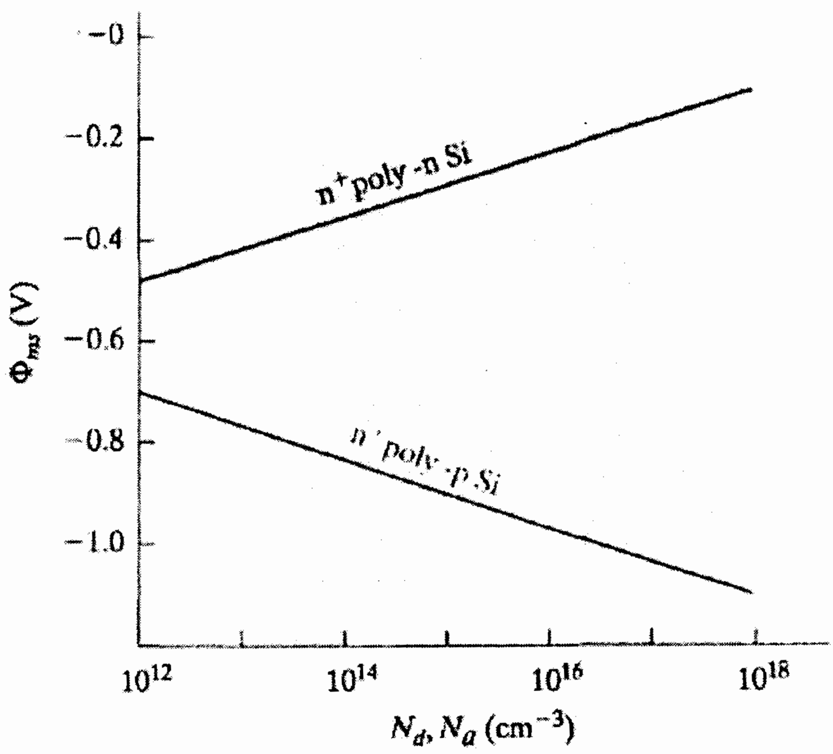
A symmetrical P+-N-P+ Si bipolar transistor has the following properties:
Area (A) = 10^{-4} cm^2, WB=1 μm

Emitter	**Base**
$N_A=2\times10^{17}$	$N_D=3\times10^{15}$ cm^{-3}
$\tau_n = 0.1\mu s$	$\tau_p = 10\mu s$

a) Calculate the saturation current $I_{ES}=I_{CS}$.
b) With V_{EB}=0.3V and V_{CB}= - 40V, calculate the base current I_B, assuming perfect emitter injection efficiency.
c) Calculation the emitter injection efficiency γ and the amplification factor β, assuming the emitter region is long compared to L_n. 4+5+(3+3)

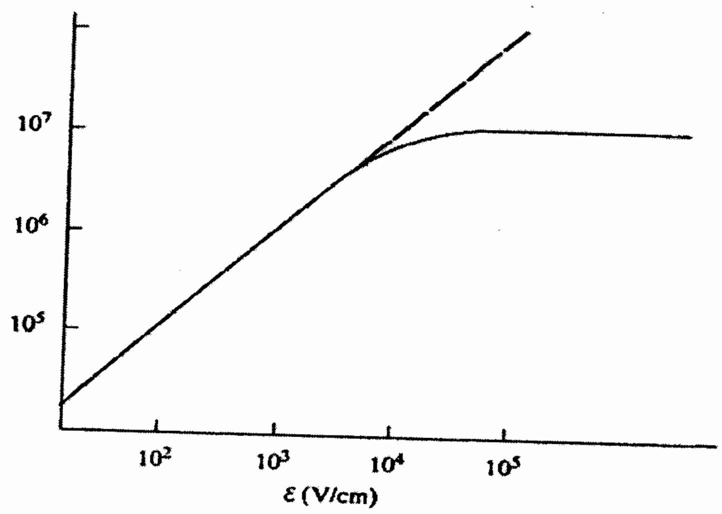
	E_g (eV)	μ_n (cm²/V-s)	μ_p (cm²/V-s)	Transition	Lattice	a (Å)	ϵ_r	Density (g/cm³)	Melting point (°C)
Si	1.11	1350	480	*i*	*D*	5.43	11.8	2.33	1415
Ge	0.67	3900	1900	*i*	*D*	5.65	16	5.32	936
SiC(α)	2.86	500		*i*	*W*	3.08	10.2	3.21	2830
AlP	2.45	80		*i*	*Z*	5.46	9.8	2.40	2000
AlAs	2.16	180		*i*	*Z*	5.66	10.9	3.60	1740
AlSb	1.6	200	300	*i*	*Z*	6.14	11	4.26	1080
GaP	2.26	300	150	*i*	*Z*	5.45	11.1	4.13	1467
GaAs	1.43	8500	400	*d*	*Z*	5.65	13.2	5.31	1238
GaSb	0.7	5000	1000	*d*	*Z*	6.09	15.7	5.61	712
InP	1.35	4000	100	*d*	*Z*	5.87	12.4	4.79	1070
InAs	0.36	22600	200	*d*	*Z*	6.06	14.6	5.67	943
InSb	0.18	10^5	1700	*d*	*Z*	6.48	17.7	5.78	525
ZnS	3.6	110		*d*	*Z, W*	5.409	8.9	4.09	1650*
ZnSe	2.7	600		*d*	*Z*	5.671	9.2	5.65	1100*
ZnTe	2.25		100	*d*	*Z*	6.101	10.4	5.51	1238*
CdS	2.42	250	15	*d*	*W, Z*	4.137	8.9	4.82	1475
CdSe	1.73	650		*d*	*W*	4.30	10.2	5.81	1258
CdTe	1.58	1050	100	*d*	*Z*	6.482	10.2	6.20	1098
PbS	0.37	575	200	*i*	*H*	5.936	161	7.6	1119
PbSe	0.27	1000	1000	*i*	*H*	6.147	280	8.73	1081
PbTe	0.29	1600	700	*i*	*H*	6.452	360	8.16	925

All values at 300 K. *vaporizes.



Variation of metal-semiconductor work-function difference with doping for n⁺-poly Si

Figure 3-24 Saturation of electron drift velocity at high electric fields for Si.



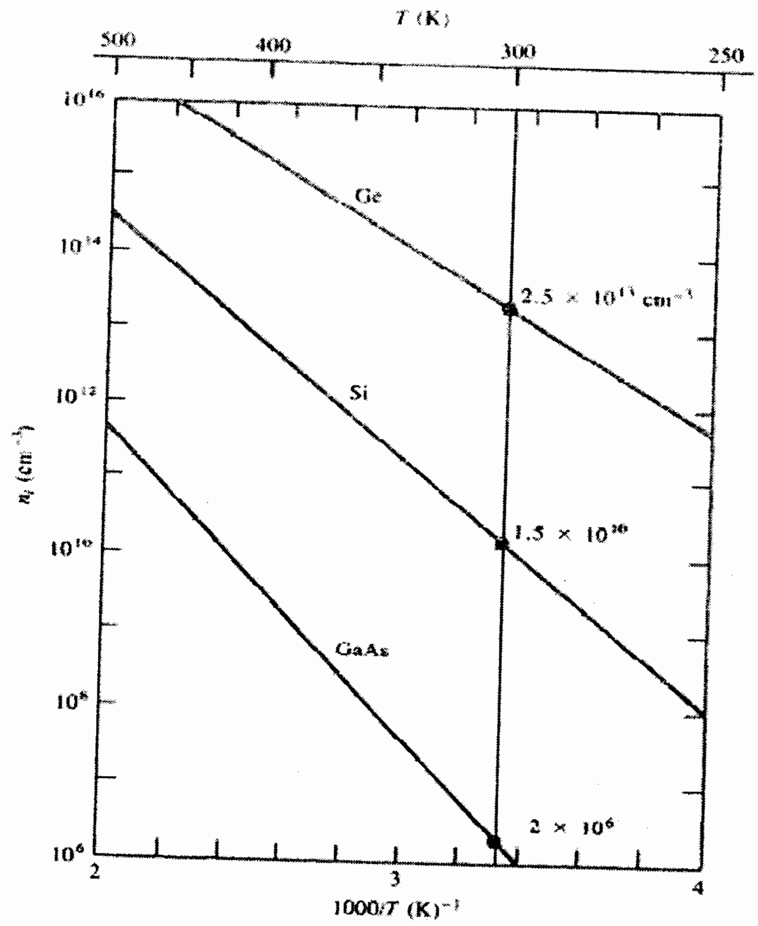


Figure 3-17 Intrinsic carrier concentration for Ge, Si, and GaAs as a function of inverse temperature. The room temperature values are marked for reference.

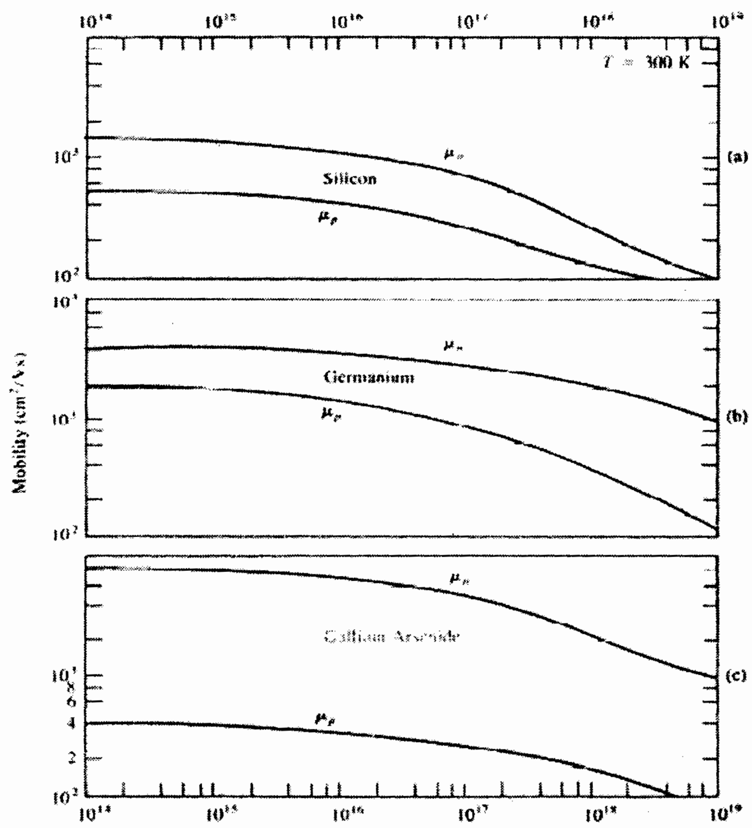


Figure 3-23 Variation of mobility with total doping impurity concentration ($N_a + N_d$) for Ge, Si, and GaAs at 300 K.

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 = 10Å = 10^{-7} cm	nano-,	n-	$= 10^{-9}$
2.54 cm = 1 in.	pico-,	p-	$= 10^{-12}$
1 eV = 1.6×10^{-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.