Semiconductor Physics – GATE Problems

1. A P-type silicon sample has higher conductivity compared to an n-type silicon sample having the same dopant concentration. TRUE/FALSE

[GATE 1994: 1 Mark]

Soln. **For a given semiconductor the electron mobility (μ_n) is always higher than hole mobility (μ_p).**

Typical values are

For S_i, $\mu_n = 1350\ cm^2/v - sec.$

$\mu_p = 480\ cm^2/v - sec.$

$Thus\ ,\qquad \mu_n > \mu_p$

Electron conductivity, $\sigma_n = nq\ \mu_n$

Hole conductivity, $\sigma_p = pq\ \mu_p$

Since, n = p (Dopant concentration is same)

q is same for both

thus $\sigma_n > \sigma_p$

Ans False

2. The Probability that an electron in a metal occupies the Fermi level, at any temperature. (> 0K)

(a) 0
(b) 1
(c) 0.5
(d) 1.0

[GATE 1995: 1 Mark]

Soln. **In metal: The probability that an electron occupies Fermi level for T>0 is 1 (since conduction and valence bands are overlapping in metals).**

In Insulator: The probability that electron occupies the Fermi level is 0.5

(Since there is small band gap in semiconductors)

Option (c)

3. The drift velocity of electrons in silicon
   (a) is proportional to the electric field for all values of electric field
   (b) is independent of the electric field
   (c) increases at low values of electric field and decreases at high values of electric field exhibiting negative differential resistance
   (d) increases linearly with electric field and gradually saturates at higher values of electric field

[GATE 1995: 1 Mark]

Soln. Drift velocity is proportional to electric filed.

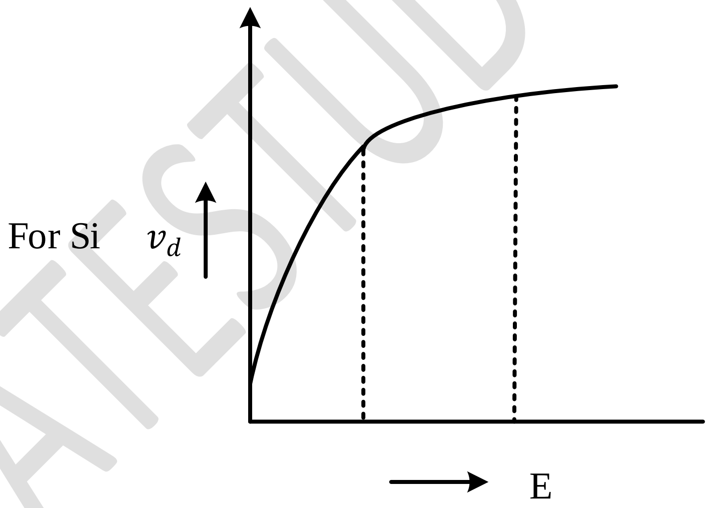
$$v_d \propto E$$

$$v_{dn} = \mu_n E$$

(Drift velocity for electrons)

Where $$\mu_n = \frac{q\tau_c}{m_n}$$

Where τ_c average time between collisions.



For small values of E, μ_n remains constant and drift velocity is proportional to E. But when E becomes very high the drift velocity saturates as shown in the given Figure

Thus option (d)

4. In a P-type Si sample the hole concentration is $2.25 \times 10^{15}/cm^3$. The intrinsic carrier Concentration is $1.5 \times 10^{10}/cm^3$ the electron concentration is

(a) Zero
(b) $10^{10}/cm^3$
(c) $10^5/cm^3$
(d) $1.5 \times 10^{25}/cm^3$

[GATE 1995: 1 Mark]

Soln. In this problem the hole concentration is given and intrinsic carrier concertation is given, we have to find electron concentration. We apply mass action law

$$\boldsymbol{n.p = n_i^2}$$

Given , $\boldsymbol{p = 2.25 \times 10^{15}\ /cm^3}$

$$\boldsymbol{n_i = 1.5 \times 10^{10}/cm^3}$$

So,

$$\boldsymbol{n = \frac{n_i^2}{p} = \frac{(1.5 \times 10^{10})^2}{2.25 \times 10^{15}}}$$

$$\boldsymbol{= \frac{2.25 \times 10^{20}}{2.25 \times 15^{15}}}$$

$$\boldsymbol{= 10^5/cm^3}$$

Option (c)

5. A small concentration of minority carries is injected into a homogeneous Semiconductor crystal at one point. An electric field of 10V/cm is applied across the crystal and this moves the minority carries a distance of 1 cm in 20 μ sec. The mobility (in cm^2/v-sec) will be

(a) 1,000
(b) 2,000
(c) 5,000
(d) 500,000

[GATE 1994: 1 Mark]

Soln. Given:

Electric field 10 $\boldsymbol{V/cm}$

Distance moved by minority carrier 1 cm.

Time taken 20 μ sec.

So, the velocity of minority

$$\textbf{Carrier} = \frac{Distance\ moved}{time\ taken}$$

$$= \frac{1\ cm}{20\times10^{-6}} = 50,000\ cm/sec$$

Drift velocity $(v_d) = \mu E$

$$or, \quad \mu = \frac{v_d}{E} = \frac{50,00}{10}$$

$$or, \quad \mu = 5000cm^2/v - s$$

Option (c)

6. The units of $\frac{q}{KT}$ are

(a) V

(b) V^{-1}

(c) J

(d) J/K

[GATE 1997: 1 Mark]

Soln. To find the units of $\frac{q}{kT}$

Unit of k (Boltzmann constant) J/K

Unit of q - Coulomb

Since the options (c) and (d) are not appropriate and the other two options are in volt

So, $\frac{q}{kT} = \frac{C}{J/K\times K} = \frac{C}{J}$

We know unit of volt is

$$1\ Joule/Coulomb$$

So, unit of $\frac{q}{kT} = \frac{1}{J/C} = \frac{1}{V} = V^{-1}$

Alternative **We know** $\frac{kT}{q} = 26\ mV$

So unit of $\frac{q}{kT} = 1/V = V^{-1}$

Option (b)

7. The intrinsic carrier concentration of silicon sample at 300^0 K is $1.5 \times 10^{16}/m^3$. If after doping, the number of majority carriers is $5 \times 10^{20}/m^3$, the minority carrier density is
(a) $4.50 \times 10^{11}/m^3$
(b) $3.33 \times 10^{4}/m^3$
(c) $5.00 \times 10^{20}/m^3$
(d) $3.00 \times 10^{-5}/m^3$

[GATE 2002: 1 Mark]

Soln. Given,

$$n_i = 1.5 \times 10^{16}/m^3$$

$$n = 5 \times 10^{20}/m^3$$

Note that concentrations are given in m^3 not in cm^3 .

$$p = \frac{n_i^2}{n} = \frac{(1.5 \times 16^{16})^2}{5 \times 10^{20}}$$

$$= \frac{2.25 \times 10^{32}}{5 \times 10^{20}}$$

$$= 45 \times 10^{10} = 4.5 \times 10^{11}$$

Option (a)

8. The band gap of silicon at 300 K is
(a) 1.36 eV
(b) 1.10 eV
(c) 0.80 eV
(d) 0.67 eV

[GATE 2002: 1 Mark]

Soln. There are standard values of the band gaps at room temp (300 K)

S_i $1.1\ ev$

G_e $0.7\ ev$

GaAs $1.41\ ev$

Option (b)

9. n – type silicon is obtained by doping silicon with

(a) Germanium
(b) Aluminum
(c) Boron
(d) Phosphorus

[GATE 2003: 1 Mark]

Soln. For n – type doped silicon pentavalent impurities are added such as

Antimony, Arsenic or Phosphorus so out of given option the correct option is (d)

10. The impurity commonly used for realizing the base region of a silicon n-p-n transistor is
(a) Gallium
(b) Indium
(c) Boron
(d) Phosphorus

[GATE 2004: 1 Mark]

Soln. The base region of n-p-n transistor is p type for p – type material the impurities of trivalent type added such as Boron, Gallium or Indium

In the present problem Boron is correct choice

Option (c)

11. The primary reason for the wide spread use of silicon in semiconductor device technology is
(a) Abundance of silicon on the surface of the Earth.
(b) Larger bandgap of silicon in comparison to germanium.
(c) Favorable properties of silicon – dioxide (sio_2)
(d) Lower melting point.

[GATE 2004: 1 Mark]

Soln. In this problem various options are given and we have to find the primary reason. Option (a) that silicon is available in abundance is correct option. Option (b) larger bandgap of Si Type equation here. **in comparison to Ge is also true. Option (c) the favorable properties of Silicon – dioxide (S_i0_2) is also right. Option (d) is not right. So out of three options which are correct the primary reason is option (a).**

Since, Silicon is available in sand which is in abundance so, option (a) is the primary reason.

12. A silicon PN junction at a temperature of 20^0 C has a reverse saturation current of 10pA. The reverse saturation current at 40^0 C for the same bias is approximately.

(a) 20 pA
(b) 30 pA
(c) 40 pA
(d) 80 pA

[GATE 2004: 1 Mark]

Soln. **We know that for Silicon PN junction every 10℃ rise in temperature, reverse saturation current doubles.**

At 20℃ reverse saturation is 10 pA.

At 30℃ reverse saturation current will be 20 pA

At 40℃ reverse saturation will be 40 pA

Option (C)

13. The band gap of silicon at room temperature is
(a) 1.3 eV
(b) 0.7 eV
(c) 1.1 eV
(d) 1.4 eV

[GATE 2005: 1 Mark]

Soln. **Band gaps for the commonly used semiconductors are**

Si	**-**	**1.1eV**
Ge	**-**	**0.7eV**
GaAs	**-**	**1.4eV**

So, for Si the value is 1.1eV

Option (c)

14. Under low level injection assumption, the injected minority carrier current for an extrinsic semiconductor is essentially the
(a) Diffusion current
(b) Drift current
(c) Recombination current
(d) Induced current

[GATE 2005: 1 Mark]

Soln. **Total current density is given by**

$$J_n = qu\, \mu_n\, E + q\, D_n \frac{dn}{dx}$$

The first term represents the drift current due to electric field (E) and second term represents diffusion current due to concentration gradient.

Because there is low level injection so n is small. First term will give negligible current. Here $\frac{dn}{dx}$ is not small.

So the current will be due to diffusion current term.

Option (a)

15. The concentration of minority carriers in an extrinsic semiconductor under equilibrium is
(a) Directly proportional to the doping concentration.
(b) Inversely proportional to the doping concentration.
(c) Directly proportional to the intrinsic concentration.
(d) Inversely proportional to the intrinsic concentration.

[GATE 2006: 1 Mark]

Soln. For n type semiconductor p (holes) represents the minority carrier concentration.

As per Mass Action law

$$\boldsymbol{n.p = n_i^2 = constant}$$

So $\boldsymbol{p \propto \frac{1}{n}}$

So, inversely proportional to doping concentration

Option (b)

16. The electron and hole concentration in an intrinsic semiconductor are n_i per cm^3 at 300^0 K. Now, if acceptor impurities are concentration of N_A per cm^3 at 300^0 K with be

(a) n_i

(b) $n_i + N_A$

(c) $N_A - n_i$

(d) $\frac{n_i^2}{N_A}$

[GATE 2007: 1 Mark]

Soln. As per law of mass action

$$n.p = n_i^2$$

Where,

n – free election concertation

p – hole concentration

n_i – intrinsic carrier concentration

Acceptor impurity N_A is hole concentration (p)

So, Electron concentration $(n) = \frac{n_i^2}{N_A}$

Option (d)

17. Which of the following is true?
    (a) A silicon wafer heavily doped with boron is a P^+ substrate.
    (b) A silicon wafer lightly doped with boron is a P^+ substrate.
    (c) A silicon wafer heavily doped with arsenic is a P^+ substrate.
    (d) A silicon wafer lightly doped with arsenic is a P^+ substrate.

[GATE 2008: 1 Mark]

Soln. Trivalent impurities such as Boron, Gallium or Indium

Are used to make P – type semiconductor

Thus, silicon wafer heavily doped with Boron in a P+ substrate.

Option (a)

18. In an n – type silicon crystal at room temperature, which of the following can have a concentration of $4 \times 10^{19}\ /cm^3$?
    (a) Silicon atoms
    (b) Holes
    (c) Dopant atoms
    (d) Valence electrons

[GATE 2009: 1 Mark]

Soln. **We should remember the order of concentrations for intrinsic and doped semiconductor. Intrinsic carrier concentration is of the order of $\cong \mathbf{1.5 \times 10^{10}/cm^3}$**

Doped semiconductor concentration is $\cong \mathbf{2 \times 10^{15}\ /cm^3}$

The given concentration is

$$\mathbf{4 \times 10^{19}\ cm^{-3}}$$

This means it is the concentration of dopant atoms, since it is more than $\cong \mathbf{10^{15}\ cm^{-3}}$

Option (c)

19. Drift current in semiconductors depends upon
(a) Only the electric field
(b) Only the carrier concentration gradient
(c) Both the electric field and the carrier concentration
(d) Neither the electric field nor the carrier concentration gradient

[GATE 2011: 1 Mark]

Soln. **Drift current is given by**

$$\boldsymbol{I_d = nq\,\mu_n\,E.}$$

From above relation we observe that drift current depends on Electric filed and carrier concentration

Option (c)

20. A silicon bar is doped with donor impurities $N_D = 2.25 \times 10^{15}\ atoms/cm^3$. Given the intrinsic carrier concentration of silicon at T = 300 K is $n_i = 1.5 \times 10^{10}\ cm^{-3}$. Assuming complete impurity ionization, the equilibrium electron and hole concentrations are
(a) $n_0 = 1.5 \times 10^{16}\ cm^{-3}, p_0 = 1.5 \times 10^{5}\ cm^{-3}$
(b) $n_0 = 1.5 \times 10^{10}\ cm^{-3}, p_0 = 1.5 \times 10^{15}\ cm^{-3}$
(c) $n_0 = 2.25 \times 10^{15}\ cm^{-3}, p_0 = 1.5 \times 10^{10}\ cm^{-3}$
(d) $n_0 = 2.25 \times 10^{15}\ cm^{-3}, p_0 = 1 \times 10^{5}\ cm^{-3}$

[GATE 2014: 1 Mark]

Soln. **Given,**

Donor impurities, $N_D = 2.25 \times 10^{15} atom/cm^3$ **when there is complete impurity ionization the number of electrons provided will be the same as Donor impurities. i.e.**

$$n = N_D = 2.25 \times 10^{15}/cm^3$$

$$P_0 = \frac{n_i^2}{n_0} = \frac{(1.5 \times 10^{10})^2}{2.25 \times 15^{15}} = \frac{2.25 \times 10^{20}}{2.25 \times 10^{15}}$$

$$= 10^5/cm^3$$

Option (d)

21. A thin P – type silicon sample is uniformly illuminated with light which generates excess carriers. The recombination rate is directly proportional to
(a) The minority carrier mobility
(b) The minority carrier recombination lifetime
(c) The majority carrier concentration
(d) The excess minority carrier concentration

[GATE 2014: 1 Mark]

Soln. A P – type sample is illuminated with light,that generates exces carriers.

Here majority carriers are holes since sample is of P – type.

When light falls on the sample minority carriers will be generated. As the minority carrier concentration increases probability of recombination increase.

Option (d)

22. At T = 300 K, the hole mobility of a semiconductor $\mu_p = 500\ cm^2/V - s$ and $\frac{kT}{q} = 26mV$. The hole diffusion constant $D_p\ in\ cm^2/s$ is

[GATE 2014: 1 Mark]

Soln. Given,

At T = 300K

Hoe mobility $(\mu_p) = 500\ cm^2/V - S$

$\frac{kT}{q} = 26\ mv$

Find hole diffusion constant .Einstein equation relates diffusivity and mobility the two important constants through the relation

$$D_P = \left(\frac{kT}{q}\right)\mu_P$$

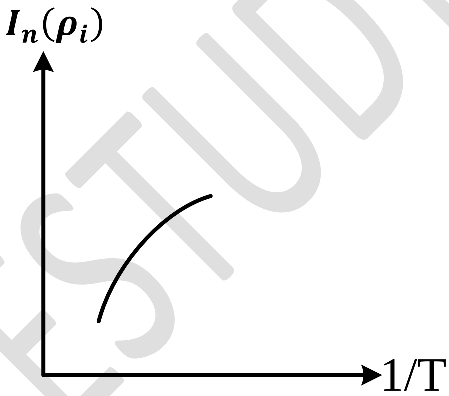
So, $D_P = \mu_P\ .V_T$

$$D_P = 500 \times 26 \times 10^{-3}$$

$$or,\ D_P = 13cm^2/S$$

Ans $13cm^2/S$

23. In the figure, $l_n(p_i)$ is plotted as function of 1/T, where p_i is the intrinsic resistivity of silicon, T is the temperature, and the plot is almost linear.



The slope of the line can be used to estimate

(a) Band gap energy of silicon (E_g)

(b) Sum of electron and hole mobility in silicon $(\mu_n + \mu_p)$

(c) Reciprocal of the sum of electron and hole mobility in silicon $(\mu_n + \mu_p)^{-1}$

(d) Intrinsic carrier concentration of silicon (n_i)

[GATE 2014: 1 Mark]

Soln. The given plot is between $l_n(\rho_i)$ and $1/T$.

As temperature (T) increases Energy gap Eg decreases Due to decrease in Eg electron hole pair generation increase. So conductivity (σ) increases. This can be represented is short as

At $T \uparrow \rightarrow E_g \downarrow \rightarrow (n\ and\ p) \uparrow \rightarrow \sigma \uparrow \rho \downarrow$

So in short As $T \uparrow \rightarrow \rho_i \downarrow$

or As $\frac{1}{T} \uparrow \rightarrow \rho_i \uparrow \rightarrow l_n(\rho_i) \uparrow$

Plot is linear

So the slope can be used to determine the band gap (Eg)

The book of S.M. Sze contains the plot of intrinsic carrier densities for S_i and GaAs as 1/T

The larger the band gap the smaller the intrinsic carrier density.

Here, option (a)

24. A silicon sample is uniformly doped with donor type impurities with a concertation of $10^{16}/cm^3$.
The electron and hole mobility's in the sample are $1200 cm^2/V - s$ and $400\ cm^2/V - s$ respectively
Assume complete ionization of impurities.
The charge of an electron is $1.6 \times 10^{-19} C$. The resistivity of the sample $in\ \Omega - cm$ is --------.

Soln. Given,

Donor impurity concentration = $10^{16}/cm^3$

$\mu_n = 1200\ cm^2/V$

$\mu_p = 400\ cm^2/V$

Conductivity

$$\sigma_N = N_D\, q\, \mu_n$$

$$= 10^{16} \times 1.6 \times 10^{-19} \times 1200$$

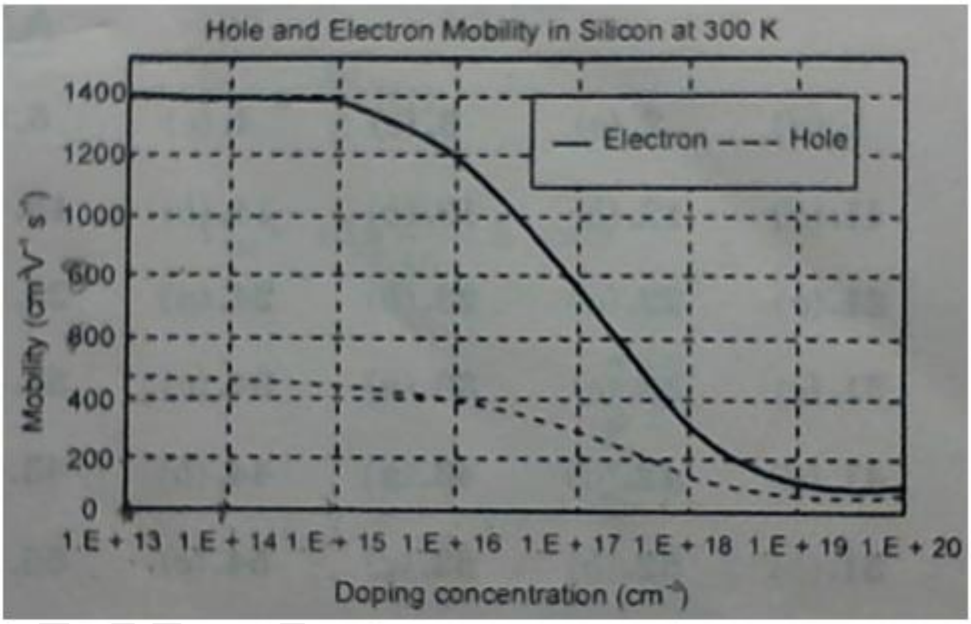
$$= 1.92\ \mho/cm$$

So, Resistivity

$\boldsymbol{\rho = \frac{1}{\sigma_N} = \frac{1}{1.92}}$

Or, $\boldsymbol{\rho = 0.52 \quad \Omega - cm}$

25. A piece of silicon is doped uniformly with phosphorous with a doping concentration of $10^{16}/cm^3$. The expected value of mobility versus doping concentration for silicon assuming full dopant ionization is shown below. The charge of an electron is $1.6 \times 10^{-19} C$. The conductivity (in S cm^{-1}) of the silicon sample at 300 K is



Soln. Given,

S_i is doped with phosphorus with doping concentration of $\boldsymbol{10^{16}/cm^3}$ **(N type)**

Plot is given for hole and electron mobility at 300K.

Conductivity $\boldsymbol{(\sigma_N) = N_D\, q\, \mu_p}$

We find the value of $\boldsymbol{\mu_P}$ **for electron for concentration of** $\boldsymbol{10^{16}/cm^3}$**. The value is** $\boldsymbol{\mu_n = 1200 cm^2/V - S}$

So, $\boldsymbol{\sigma_N = 10^6 \times 1.6 \times 10^{-19} \times 1200 = 1.92\ Siemens/cm}$

Ans 1.92 S/cm