Chapter 14
Semiconductor Electronics material device

EXERCISE

Question 1:

In an n-type silicon, which of the following statements is true:

(a) Electrons are majority carriers and trivalent atoms are the dopants.

(b) Electrons are minority carriers and pentavalent atoms are the dopants.

(c) Holes are minority carriers and pentavalent atoms are the dopants.

(d) Holes are majority carriers and trivalent atoms are the dopants.

Solution 1:

The correct statement is (c).

In an n-type silicon, the electrons are the majority carriers, while the holes are the minority carries. An n-type semiconductor is obtained when pentavalent atoms, such as phosphorus, are doped in silicon atoms.

Question 2:

Which of the statements given in Exercise 14.1 is true for p-type semiconductor.

Solution 2:

The correct statement is (d).

In a p-type semiconductor, the holes are the majority carriers, while the holes are the minority carries. A p-type semiconductor is obtained when trivalent atoms, such aluminium, are doped in silicon atoms.

Question 3:

Carbon, silicon and germanium have four valence electrons each. These are characterized by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_C$, $(E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statements is true?

(a) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$

(b) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$

(c) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

(d) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

Solution 3:

The correct answer is (c).

Of the three given elements, the energy band gap of carbon is the maximum and that germanium is the least.

The energy bang gap of the these elements are related as : $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

Question 4:

In an unbiased p-n junction, holes diffuse from the p-region to n-region because

(a) Free electrons in the n-region attract them.

(b) They move across the junction by the potential difference.

(c) Hole concentration in p-region is more as compared to n-region.

(d) All the above.

Solution 4:

The correct statement is (c).

The diffusion of charge carriers across a junction takes place from the region of higher concentration to the region of lower concentration. In this case, the p-region has greater concentration of holes than the n-region. Hence, in an unbiased p-n junction, holes diffuse from the p-region to the n-region.

Question 5:

When a forward bias is applied to a p-n junction, it

(a) Raises the potential barrier.

(b) Reduce the majority carrier current to zero.

(c) Lower the potential barrier.

(d) None of the above.

Solution 5:

The correct statement is (c).

When forward bias is applied to a p-n junction, it lower the values of potential barrier. In the case of forward bias, the potential barrier is opposed by the applied voltage. Hence, the potential barrier across the junction gets reduced.

Question 6:

For transistor action, which of the following statements are correct.

(a) Base, emitter and collector regions should have similar size and doping concentrations.

(b) The base region must be very thin and lightly doped.

The emitter junction is forward biased and collector junction is reverse biased.

Both the emitter junction as well as the collector junction are forward biased.

Solution 6:

The correct statement is (b), (c).

For a transistor action, the base region must be lightly doped so that the base region is very thin. Also, the emitter junction must be forward-biased and collector junction should be reversed-biased.

Question 7:

For a transistor amplifier, the voltage gain

(a) Remains constant for all frequencies.

(b) Is high at high and low frequencies and constant in the middle frequency range.

(c) Is low at high and low frequencies and constant at mid frequencies.

(d) None of the above.

Solution 7:

The correct statement is (c).

The voltage gain of a transistor amplifier is constant at mid frequency range only. It is low at high and low frequencies.

Question 8:

In half-wave rectifier, what is the output frequency if the input frequency is 50Hz. What is the output frequency of a full-wave rectifier for the same input frequency

Solution 8:

Input frequency = 50Hz

For a half-wave rectifier, the output frequency is equal to the input frequency.

$\therefore$ Output frequency = 50Hz

For a full-wave rectifier, the output frequency is twice the input frequency.

$\therefore$ Output frequency = $2 \times 50 = 100$ Hz

Question 9:

For a CE-transmitter amplifier, the audio signal voltage across the collector resistance of 2 $k\Omega$ is 2 V. Suppose the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1 $k\Omega$.

Solution 9:

Collector resistance, $R_c = 2\ k\Omega = 2000\ \Omega$

Audio signal voltage across the collector resistance, V = 2 V

Current amplification factor of the transistor, $\beta = 100$

Base resistance, $R_B = 1\ k\Omega = 1000\ \Omega$

Input signal voltage = V_i

Base current = I_B

We have the amplification relation as :

Voltage amplification $= \frac{V}{V_i} = \beta \frac{R_C}{R_B}$

$$V_i = \frac{V}{\beta} \frac{R_B}{R_C}$$

$$= \frac{2 \times 1000}{100 \times 2000} = 0.01V$$

Therefore, the input signal voltage of the amplifier is 0.01V.

Base resistance is given by the relation:

$$R_B = \frac{V_i}{V_B}$$

$= 0.01/1000 = 10^{-6}$A

Therefore, the base current of the amplifier is $10\mu A$.

Question 10:

Two amplifier are connected one after the other in series (cascaded). The first amplifier has a voltage gain of 10 and the second has a voltage gain of 20. If the input signal is 0.01 volt, calculate the output ac signal.

Solution 10:

Voltage gain of the first amplifier, $V_1 = 10$

Voltage gain of the second amplifier, $V_2 = 20$

Input signal voltage, $V_i = 0.01V$

Output AC signal voltage $= V_o$

The total voltage gain of a two-stage cascaded amplifier is given by the product of voltage gains of both the stages, i.e.,

$V = V_1 \times V_2$

$= 10 \times 20 = 200$

We have the relation:

$V = \frac{V_o}{V_i}$

$V_o = V \times V_i$

$= 200 \times 0.01 = 2V$

Therefore, the output AC signal of the given amplifier is 2V.

Question 11:

A p-n photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Can it detect a wavelength of 6000 nm?

Solution 11:

Energy band gap of the given photodiode, E_g = 2.8 eV

Wavelength, $\lambda = 6000\,nm = 6000 \times 10^{-9}\,m$

The energy of a signal is given by the relation:

$E = \frac{hc}{\lambda}$

Where,

h = Planck's constant

$= 6.626 \times 10^{-34}\,Js$

C = speed of light

$= 3 \times 10^8$ m/s

$E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{6000 \times 10^{-9}}$

$= 3.313 \times 10^{-20}\,J$

But $1.6 \times 10^{-20}\,J = 1eV$

$\therefore E = 3.313 \times 10^{-20}\,J$

$= \frac{3.313\times10^{-20}}{1.6\times10^{-19}} = 0.207eV$

The energy of signal of wavelength 6000 nm is 0.207 eV, which is less than 2.8 eV- the energy band gap of a photodiode. Hence, the photodiode cannot detect the signal.

Additional Exercises

Question 12:

The number of silicon atoms per m^3 is 5×10^{28}. This is doped simultaneously with 5×10^{22} atoms per m^3 of Arsenic and 5×10^{20} per m^3 atoms of indium. Calculate the number of electrons and holes. Given that $n_i = 1.5\times10^{16} m^{-3}$. Is the material n-type or p-type?

Solution 12:

Number of silicon atoms, $N = 5\times10^{28} atoms/m^3$

Number of arsenic atoms, $n_{as} = 5\times10^{22} atoms/m^3$

Number of indium atoms, $n_{In} = 5\times10^{20} atoms/m^3$

Number of thermally-generated electrons, $n_i = 1.5\times10^{16} electrons/m^3$

Number of electrons, $n_e = 5\times10^{22} - 1.5\times10^{16} \approx 4.99\times10^{22}$

Number of holes = n_h

In thermal equilibrium, the concentration of electrons and holes in a semiconductor are related as:

$n_e n_{h=} n_i^2$

$\therefore n_h = \frac{n_i^2}{n_e}$

$= \frac{\left(1.5\times10^{16}\right)^2}{4.99\times10^{22}} \approx 4.51\times10^{9}$

Therefore, the number of electrons is approximately 4.99×10^{22} and the number of holes is about 4.51×10^{9}. Since the number of electrons is more than the number of holes, the material is an n-type semiconductor.

Question 13:

In an intrinsic semiconductor the energy gap E_g is 1.2 eV. Its hole mobility is much smaller than electron mobility and independent of temperature. What is the ratio between conductivity at 600K and that at 300k? Assume that the temperature dependence of intrinsic carrier concentration n_i is given by $n_i = n_0 \exp\left(-\frac{E_g}{2k_BT}\right)$

Where n_0 is constant

Solution 13:

Energy gap of the given intrinsic semiconductor, $E_g = 1.2eV$

The temperature dependence of the intrinsic carrier-concentration is written as:

$$n_i = n_0 \exp\left(-\frac{E_g}{2k_BT}\right)$$

Where,

k_B = Boltzmann constant = $8.62\times10^{-5} eV/k$

T = Temperature

n_0 = constant

Initial temperature, $T_1 = 300k$

The intrinsic carrier-concentration at this temperature can be written as:

$$n_{i1} = n_0 \exp\left[-\frac{E_g}{2k_B\times300}\right]_{....(1)}$$

Final temperature, $T_2 = 600K$

The intrinsic carrier-concentration at this temperature can be written as:

$$n_{i2} = n_0 \exp\left[-\frac{E_g}{2k_B\times600}\right]_{...(2)}$$

The ratio between the conductivities at 600K and at 300K is equal to the ratio between the respective intrinsic carrier-concentrations at these temperatures.

$$\frac{n_{i2}}{n_{i1}} = \frac{n_0 \exp\left[-\frac{E_g}{2k_B 600}\right]}{n_0 \exp\left[-\frac{E_g}{2k_B 300}\right]}$$

$$= \exp\frac{E_g}{2k_B}\left[\frac{1}{300} - \frac{1}{600}\right] = \exp\left[\frac{1.2}{2\times 8.62\times 10^{-5}} \times \frac{2-1}{600}\right]$$

$$= \exp[11.6] = 1.09\times 10^5$$

Therefore, the ratio between the conductivities is 1.09×10^5.

Question 14:

In a p-n junction diode, the current I can be expressed as $I = I_0 \exp\left(\frac{eV}{2k_B T} - 1\right)$

Where I_0 is called the reverse saturation current, V is the voltage across the diode and is positive for forward bias and negative bias, and I is the current through the diode, k_B is the Boltzmann constant $(8.6\times 10^{-5} eV/K)$ and T is the absolute temperature. If for a given diode $I_0 = 5\times 10^{-12}$ A and T =300 K, then

(a) What will be the forward current at a forward voltage of 0.6 V?

(b) What will be the increase in the current if the voltage across the diode is increased to 0.7 V?

(c) What is the dynamic resistance?

(d) What will be the current if reverse bias voltage changes from 1V to 2V?

Solution 14:

In a p-n junction diode, the expression for current is given as:

$$I = I_0 \exp\left(\frac{eV}{2k_B T} - 1\right)$$

Where,

I_0 = Reverse saturation current $= 5\times 10^{-12} A$

T = Absolute temperature = 300K

k_B = Boltzmann constant $= 8.6\times 10^{-5} eV/K = 1.376\times 10^{-23} JK^{-1}$

V = Voltage across the diode

(a) Forward voltage, V = 0.6 V

$$= 5\times10^{-1}\left[\exp\left(\frac{1.6\times10^{-19}\times0.6}{1.376\times10^{-23}\times300}\right)-1\right]$$

$\therefore$ Current, I

$$= 5\times10^{-12}\times\exp\left[22.36\right] = 0.063A$$

Therefore, the forward current is about 0.063A

(b) For forward voltage, V=0.7 V, we can write:

$$I = 5\times10^{-12}\left[\exp\left(\frac{1.6\times10^{-19}\times0.7}{1.376\times10^{-23}\times300}-1\right)\right]$$

$$= 5\times10^{-12}\times\exp\left[26.25\right] = 2.972A$$

Hence, the increase in current, $\Delta I = I = I$

=1.257 – 0.0256 = 1.23 A

(c)

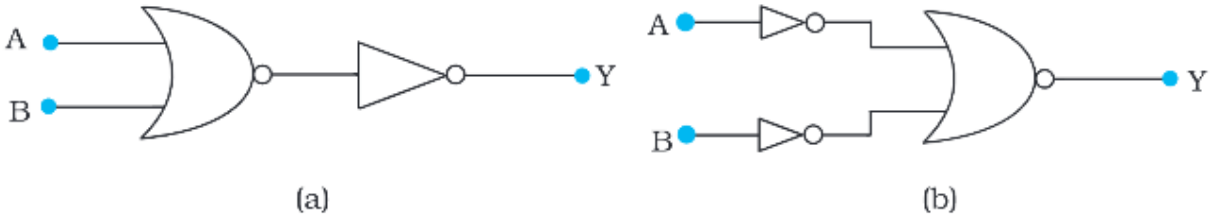
$$\text{Dynamic resistance} = \frac{Change\ in\ voltage}{Change\ in\ current}$$

= (0.7 – 0.6A)/ 2.972 = 0.0336/ Ω

(d) If the reverse bias voltage changes from 1V to 2V, then the current (I) will almost remain equal to I_0 in both cases. Therefore, the dynamic resistance in the reverse bias will be infinite.

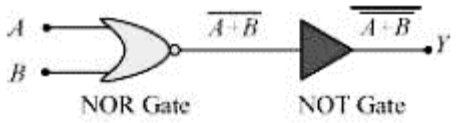
Question 15:

You are given he two circuits as shown in figure. Show that current (a) acts as OR gate while the circuit (b) acts as AND gate.



Solution 15:

(a) A and B are the inputs and Y is the output of the given circuit. The left half of the given figure acts as the NOR Gate, while the right half acts as the NOT Gate. This is shown in the following figure.



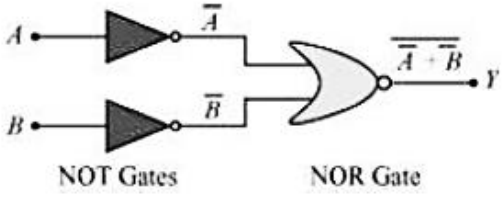
Hence, the output of the NOR Gate $=\overline{A+B}$

This will be the input for the NOT Gate. Its output will be $\overline{\overline{A+B}} = A+B$

$\therefore Y = A+B$

Hence, this circuit fuctions as on OR Gate.

(b) A and B are the inputs and Y is the output of the given circuit (b) A and B are the Inputs and Y is the output of the given circuit. It can be observed from the following figure that the Inputs of the right half NOR Gate are the outputs of the two note Gates.



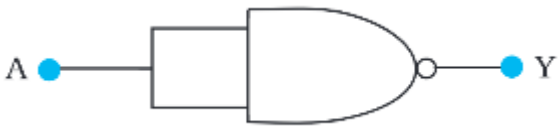
Hence, the ouput of the given circuit can be written as:

$Y = \overline{\overline{A}+\overline{B}} = \overline{\overline{A}}.\overline{\overline{B}} = A.B$

Hence, this circuit functions as an AND Gate.

Question 16:

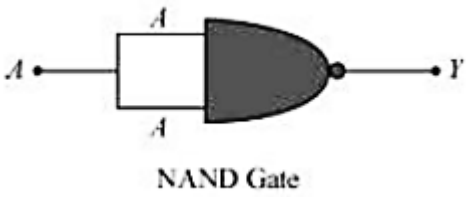
Write the truth table for a NAND Gate connected as given in figure.



Hence identify the exact logic opreation carried out by this circuit.

Solution 16:

A acts as the two inputs of the NAND gate and Y is the output, as shown in the following figure.



NAND Gate

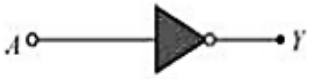
Hence, the output can be written as :

$Y = \overline{A.A} = \overline{A} + \overline{A} = \overline{A}$ …(i)

The truth table for equation (i) can be drawn as :

A	$Y^{(=\overline{A})}$
0	1
1	0

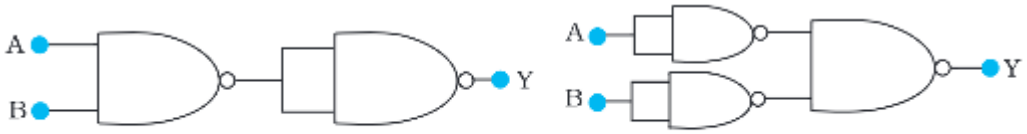
This circuit fuctions as a NOT gate. The symbol for this logic circuit is shown as:



NOT Gate

Question 17:

You are given two circuits as shown In figure, which consist of NAND gates. Identify the logic operation carried out by the two circuits.

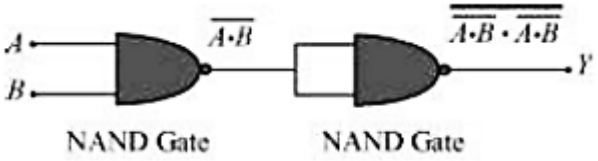


(a) (b)

Solution 17:

In both the given circuits, A and B are the inputs and Y is the output.

(a) The output of the left NAND gate will be $\overline{A.B}$, as shown in the following figure.



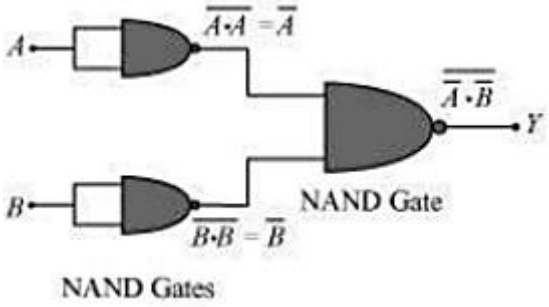
NAND Gate NAND Gate

Hence, the ouput of the combination of the two NAND gate is given as:

$Y = \overline{\left(\overline{A \cdot B}\right) \cdot \left(\overline{A \cdot B}\right)} = \overline{\overline{AB}} + \overline{\overline{AB}} = AB$

Hence, this circuit functions as an AND gate.

(b) $\overline{A}$ is the output of the upper left of the NAND gate and $\overline{B}$ is the output of the lower half of the NAND gate, as shown in the following figure.



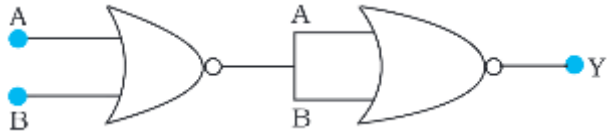
Hence, the ouput of the combination of the NAND gates will be given as:

$Y = \overline{A} \cdot \overline{B} = \overline{\overline{A}} + \overline{\overline{B}} = A + B$

Hence, this circuit functions as an OR gate.

Question 18:

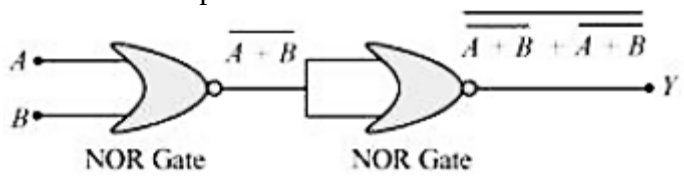
Write the truth table for circuit given in figure below consisting of NOR gates and identify the logic operation (OR, AND, NOT) which this circuit is performing.



(Hint: A = O, B = 1 then A and B inputs of second NOR gate will be O and hence Y=1.Similarly work out the values of Y for other combinations of A and B. Compare with the truth table of OR, AND, NOT gates and find the correct one.)

Solution 18:

A and B are the inputs of the given circuit. The output of the first NOR gate is $\overline{A+B}$ it can be observed from the following figure that the inputs of the second NOR gate become the output of the first one.



Hence, the output of the combination is given as:

$Y = \overline{\overline{A+B}+\overline{A+B}} = \overline{\overline{A}\cdot\overline{B}}+\overline{\overline{A}\cdot\overline{B}}$

$= \overline{\overline{A}\cdot\overline{B}} = \overline{\overline{A}}+\overline{\overline{B}} = A+B$

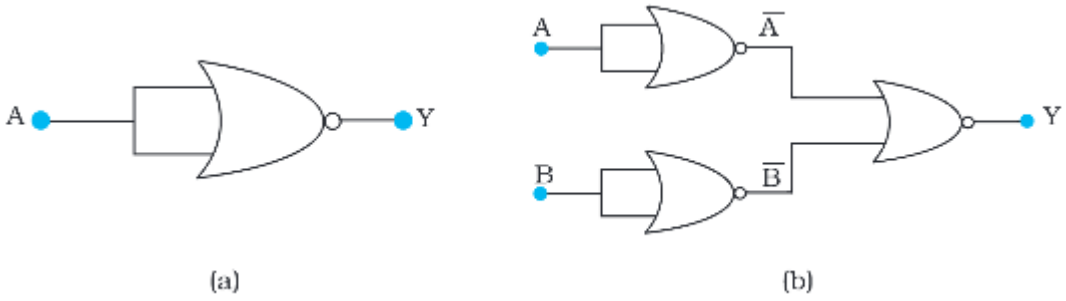
The truth table for this operation is given as:

A	B	Y(=A+B)
0	0	0
0	1	1
1	0	1
1	1	1

This is the truth table of an OR gate. Hence, this circuit functions as an OR gate.

Question 19:

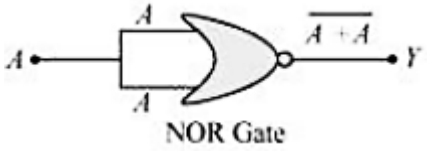
Write the truth table for the circuits given in figure consisting of NOR gates only. Identify the logic operations (OR, AND, NOT) performed by the two circuits.



(a) (b)

Solution 19:

A acts as the two input of the NOR gate and Y is the output, as shown in the following figure. Hence, the output of the circuit $\overline{A+B}$.



NOR Gate

Output, $Y = \overline{A+A} = \overline{A}$

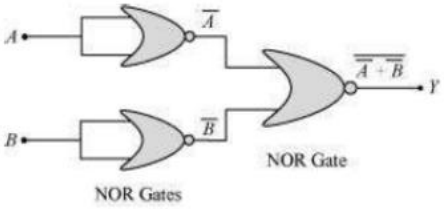
The truth table for the same is given as:

A	$Y^{(=\overline{A})}$
0	1

1	0

This is the truth table of a NOT gate. Hence, this circuit functions as a NOT gate.

(b) A and B are the inputs and Y is the output of the given circuit. By using the result obtained in solution (a) we can infer that the outputs of the first two NOR gates are $\overline{A} and \overline{B}$, as shown in the following figure.



$\overline{A} and \overline{B}$ are the inputs for the last NOR gate. Hence, the output for the circuit can be written as:

$$Y = \overline{\overline{A}+\overline{B}} = \overline{\overline{A}}\cdot\overline{\overline{B}} = A\cdot B$$

The truth table for the same can be written as:

A	**B**	$Y(=A-B)$
0	0	0
0	1	0
1	0	0
1	1	1

This is the truth table for an AND gate. Hence, this circuit function as AND gate.