CHAPTER - 14

SEMICONDUCTOR ELECTRONICS MATERIALS DEVICES AND SIMPLE CIRCUITS

Q. 14.1 In an n-type silicon, which of the following statement 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.

Answer:

An N-type semiconductor has electron as majority carriers and holes as minority carriers. It is formed when we dope pentavalent impurity in Silicon atom. Some pentavalent dopants are phosphorus, arsenic, and bismuth.

Hence the correct option is C.

Q. 14.2 Which of the statements given in Exercise 14.1 is true for p-type semiconductors.

(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

Answer:

In a p-type semiconductor, holes are the majority carrier and electrons are the minority carrier. It is formed when a trivalent atom-like aluminium is doped in a silicon atom. Hence correct option for p-type conductor would be (d).

Q. 14.3 Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separated by energy bandgap respectively equal to $(Eg)_C, (E_g)_{Si}$ and $(Eg)_{Ge}$. 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) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

Answer:

Since carbon is a non-metal, its energy band gap would be highest and energy band gap of Ge would be least as it is a metalloid.

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

Hence correct option would be (c)

Q14.4 In an unbiased p-n junction, holes diffuse from the p-region to n-region beca

(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

Answer:

Charge flows from higher concentration to the lower concentration in a junction. In this case, holes are diffusing from the p-region to n-region and hence the concentration of hole is greater in p region.

And hence correct option would be (c)

Q. 14.5 When a forward bias is applied to a p-n junction, it

(a) raises the potential barrier

(b) reduces the majority carrier current to zero.

(c) lowers the potential barrier.

(d) none of the above.

Answer:

When a p-n junction is forward biased, the negative voltage repels the electron toward junction and give them the energy to cross the junction and combine with the hole which is also being pushed by a positive voltage. This leads to a reduction in the depletion layer which means a reduction in potential barrier across the junction.

Hence correct option would be (c)

Q. 14.6 In half-wave rectification, what is the output frequency if the input frequency is $50\ Hz$ What is the output frequency of a full-wave rectifier for the same input frequency

Answer:

As we know :

Output frequency for half-wave rectifier = input frequency, and hence output frequency in half-wave rectifier will be 50Hz.

Also, output frequency for full-wave rectifier = 2*(input frequency) and Hence output frequency in full-wave rectifier will be 2*50 = 100 Hz.

Q. 14.7 A p-n photodiode is fabricated from a semiconductor with bandgap of $2.8\ eV$ Can it detect a wavelength of $6000\ nm$?

Answer:

Given

the energy band gap of photodiode is 2.8eV.

wavelength = λ = 6000nm = 6000×10^{-9}

The energy of signal will be $\frac{hc}{\lambda}$

where c is speed of light(300000000m/s) , h is planks constant (= $6.626 \times 10^{-34}\ Js$)

putting the corresponding value

The energy of signal = $\frac{(6.626\times10^{-34}\times3\times10^{8}}{6000\times10^{-9}}$

= $3.313\times10^{-20}\,J$

= $0.207\;eV\;(since\;1.6\times10^{-20}=1eV)$

The energy of the signal is 0.207eV which is less than 2.8eV (the energy and gap of photodiode). Hence signal cannot be detected by the photodiode.

Q. 14.8 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 $p-type$?

Answer:

Given:

number of Silicon atoms per $m^3=5\times10^{28}$

number of Arsenic atoms per $m^3=5\times10^{22}$

number of Indium atoms per $m^3=5\times10^{20}$

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

Now,

Number of electrons

$$n_e=5\times10^{22}-1.5\times10^{16}=4.99\times10^{22}\;(approx)$$

number of holes is n_h

in thermal equilibrium

$$n_h\times n_e=n_i^2$$

$$n_h=n_i^2/n_e$$

$$n_h=(1.5\times10^{16})^2/4.99\times10^{22}$$

$$n_h=4.51\times10^{9}$$

Now, since the number of electrons is higher than number of holes, it is an n-type semiconductor.

Q. 14.9 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.

Answer:

Energy gap of given intrinsic semiconductor = E_g = 1.2eV

temperature dependence of intrinsic carrier concentration n_i is given by

$$n_i = n_0\ exp\ \left[-\frac{E_g}{2K_BT}\right]$$

Where is constant, K_B is Boltzmann constant = $8.862 \times 10^{-5} eV/K,$

T is temperature

Initial temperature = T1 = 300K

the intrinsic carrier concentration at this temperature :

$$n_{i1} = n_0\ exp\ \left[\frac{-E_g}{2K_B \times 300}\right]$$

Final temperature = T2 = 600K

The intrinsic carrier concentration at this temperature :

$$n_{i2} = \ n_0\ exp \left[\frac{-E}{2K_B \times 600}\right]$$

The ratio between the conductivities at 300K and at 600K is equal to the ratio of their intrinsic carrier concentration at these temperatures

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

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

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

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

Q. 14.10 (a) In a p-n junction diode, the current I can be expressed as

$$I = I_0 \left[exp\frac{eV}{K_BT} - 1\right]$$

where I_0 is called the reverse saturation current, V is the voltage across the diode and is positive for forward bias and negative for reverse 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 $0.6\ V$?

Answer:

As we have

$$I = I_0 \left[exp\frac{eV}{K_BT} - 1\right]$$

Here, $I_0 = 5 \times 10^{-12}A$, $T = 300\ K$ and , k_B = Boltzmann constant = $(8.6 \times 10^{-5}\ eV/K) = 1.376 \times 10^{-23}\ J/K)$

When the forward voltage is 0.6V:

$I = I_0\left[exp\frac{eV}{K_BT} - 1\right]$

Hence forward current is 0.0625A

Q.14.10 (b) In a p-n junction diode, the current I can be expressed as

$$I = I_0\left[exp\frac{eV}{K_BT} - 1\right]$$

where I0 is called the reverse saturation current, V is the voltage across the diode and is positive for forward bias and negative for reverse 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

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

Answer:

As we have

$I = I_0\left[exp\frac{eV}{K_BT} - 1\right]$

Here, $I_0 = 5 \times 10^{-12}A$, $T = 300\ K$ and , k_B = Boltzmann constant = $(8.6 \times 10^{-5}\ eV/K) = (1.376 \times 10^{-23}\ J/K)$

When the forward voltage is 0.7V:

$$I = 5 \times 10^{-12}\ \left[exp\frac{1.6 \times 10^{-19}\square \times 0.7}{1.376 \times 10^{-23} \times 300} - 1\right] = 3.029\ A$$

When the forward voltage is 0.6V:

$$I = 5 \times 10^{-12}\ \left[exp\frac{1.6 \times 10^{-19}\square \times 0.6}{1.376 \times 10^{-23} \times 300} - 1\right] = 0.0625\ A$$

Hence the increase in the forward current is

$$I\ (when\ v = 0.7) - I(when\ v = .6) = 3.029 - 0.0625 = 2.967\ A$$

Q. 14.10 (c) In a p-n junction diode, the current I can be expressed as

$$I = I_0\left[exp\frac{eV}{K_BT} - 1\right]$$

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

(c) What is the dynamic resistance?

Answer:

Dynamic Resistance = $\frac{voltage-change}{current-change}$

Resistance change = 0.7 - 0.6 = 0.1

Current change = 2.967(calculated in prev question)

Therefore,

$$Dynamic\ Resistance = \frac{0.1}{2.967} = 0.0337\Omega$$

Q.14.10 (d) In a p-n junction diode, the current I can be expressed as

$$I = I_0\left[exp\frac{eV}{K_BT} - 1\right]$$

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

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

Answer:

As we have

$$I = I_0\left[exp\frac{eV}{K_BT} - 1\right]$$

Here, $I_0 = 5 \times 10^{-12}A$, $T = 300\ K$ and , k_B = Boltzmann constant = $(8.6 \times 10^{-5}\ eV/K) = (1.376 \times 10^{-23}\ J/K)$

When reverse voltage is 1V, V= -1

$$I = 5 \times 10^{-12}\left[exp\frac{1.6 \times 10^{-19} \times (-1)}{1.376 \times 10^{-23} \times 300} - 1\right] \approx 5 \times 10^{-12}$$

When the reverse voltage is -2V:

$$I = 5 \times 10^{-12}\left[exp\frac{1.6 \times 10^{-19} \times (-2)}{1.376 \times 10^{-23} \times 300} - 1\right] \approx 5 \times 10^{-12}$$

In both case current is very small and approximately equal to the reverse saturation current, hence their difference is negligible which causes dynamic resistance of infinity.

Q. 14.11 (a) You are given the two circuits as shown in Fig. 14.36. Show that circuit

(a) acts as OR gate while the circuit

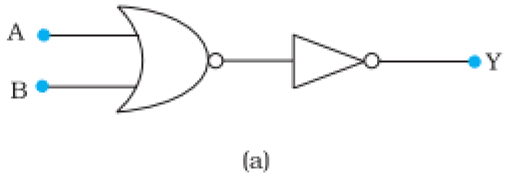


Fig. 14.36

Answer:

Here, THE Input = A and B

Output = Y

The left part of the figure acts as a NOR and right part acts as NOT Gate.

The output of NOR gate = $\overline{A+B}$

the output of the NOR gate would be the input of NOT Gate and hence

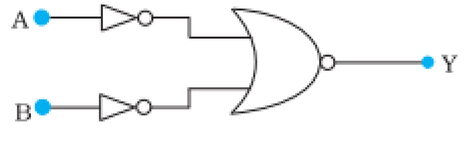
$$Y = \overline{\overline{A+B}} = A + B$$

Hence the figure functions like an OR Gate.

or compare the truth table by giving different input and observing the output

INPUTS		**OUTPUT**
A	**B**	**Y**
0	**0**	**0**
0	**1**	**1**
1	**0**	**1**
1	**1**	**1**

Q. 14.11 (b) You are given the two circuits as shown in Fig. 14.36. Show that circuit (b) acts as AND gate.



(b)

Answer:

The output of NOT gate (left part of the circuit) is the input of the NOR gate

Hence the output of total circuit Y = $\overline{(\bar{A} + \bar{B})}$

$= \bar{\bar{A}}.\bar{\bar{B}}$ $\qquad\qquad \overline{A + B} = \bar{A}.\bar{B}$

$$= A \times B$$

Hence the circuit functions as AND gate.

or give the inputs 00,01,10,11 and observe the truth table

INPUTS		**OUTPUT**
A	**B**	**Y**
0	**0**	**0**

INPUTS		OUTPUT
0	**1**	**0**
1	**0**	**0**
1	**1**	**1**

The truth table is the same as that of AND gate

Q. 14.12 Write the truth table for a NAND gate connected as given in Fig. 14.37

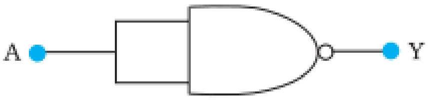


FIGURE 14.37

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

Answer:

Here A is both input of the NAND gate and hence Output Y will be

$$Y = \overline{A \times A}$$

$$Y = \bar{A} + \bar{A}$$

$$Y = \bar{A}$$

Hence circuit functions as a NOT gate.

The truth table for the given figure:

Input	Output
A	**Y**
0	**1**
1	**0**

Q 14.13 You are given two circuits as shown in Fig. 14.38, which consist of NAND gates. Identify the logic operation carried out by the two circuits.

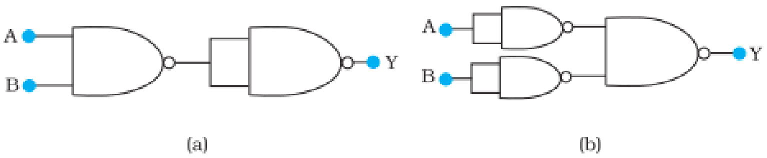


FIGURE 14.38

Answer:

a)

A and B are inputs of a NAND gate and output of this gate is the input of another NAND gate so,

$$Y = \overline{\overline{(A.B)}\ \overline{(A.B)}}$$

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

$$Y = AB$$

Hence this circuit functions as AND gate.

b)

A is input to the NAND gate output of whose goes to the rightmost NAND gate. Also, B is input to the NAND gate whose output goes to the rightmost NAND gate.

Y = $\overline{\bar{A}\,.\,\bar{B}}$

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

Y = A + B

Hence the circuit functions as an OR gate .

Alternative method

fig. a

construct the truth table by giving various input and observe the output

INPUT	**INTERMEDIATE OUTPUT**	**OUTPUT**
00	**1**	**0**
01	**1**	**0**
10	**1**	**0**
11	**0**	**1**

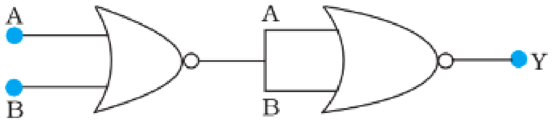
The above truth table is the same as that of an AND gate

fig. b

INPUTS	**OUTPUT**
00	**0**
01	**1**
10	**1**
11	**1**

The above truth table is the same as that of an OR gate

Q. 14.14 Write the truth table for the circuit given in Fig. 14.39 below consisting of NOR gates and identify the logic operation (OR, AND, NOT) which this circuit is performing.



(Hint: $A = 0, B = 1$ then A and B inputs of second NOR gate will be 0 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.)

Answer:

A and B are the input od a NOR gate and Output of this NOR gate is the Input of Another NOR gate whose Output is Y. Hence,

Y = $\overline{(\overline{A+B} + \overline{A+B})}$

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

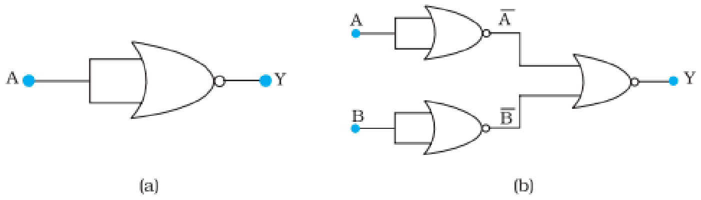
Y = A + B

Hence Circuit behaves as OR gate.

Truth table

INPUTS	**OUTPUT**
00	**0**
01	**1**
10	**1**
11	**1**

Q. 14.15 Write the truth table for the circuits given in Fig. 14.40 consisting of NOR gates only. Identify the logic operations (OR, AND, NOT) performed by the two circuits.



(a) (b)

Figure 14.40

Answer:

a)

A is the two input of the NOR gate and Hence Output Y is:

Y = $\overline{A + A}$

Y = $\overline{A}$

Hence circuit functions as a NOT gate.

TRUTH TABLE:

INPUT	**OUTPUT**
0	**1**
1	**0**

b) A is the two input of a NOR gate whose output (which is $\bar{A}$) is the one input of another NOR gate. B is the two input of NOR gate whose output (which is $\bar{B}$) is the input of another NOR gate. Hence,

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

Y = $\bar{\bar{A}} . \bar{\bar{B}}$

Y = A.B

Hence it functions as AND gate.

TRUTH TABLE:

INPUTS	**OUTPUT**
00	**0**
01	**0**
10	**0**
11	**1**