Tribhuvan University

Institute of Science and Technology

2075

Bachelor Level / First Year/ First Semester/ Science
Computer Science and Information Technology (PHY. 113)
(Physics)
(NEW COURSE)

Full Marks: 60
Pass Marks: 24
Time: 3 hours.

Candidates are required to give their answers in their own words as far as practicable.
The figures in the margin indicate full marks.

Attempt any two questions: (10×2=20)

1. Explain the process of semiconductor purification by describing the terms Zone refining, Single crystal growth, and scheme of IC production. Give an account of electronic component fabrication on a chip. (10)

2. Set up differential equation for an oscillation of a spring using Hooke's and Newton's second law. Find the general solution of this equation and hence the expressions for period, velocity and acceleration of oscillation. (10)

3. Describe Frank Hertz experiment. Discuss its result and outline limitations. (10)

Attempt any eight questions: (5×8=40)

4. Discuss magnetic dipole moment. What is its effect on atom and on molecules? Explain. (5)

5. Explain Bloch theorem? Discuss its use in Kronig-Penny model and hence in band theory. (5)

6. Explain the construction and working of bipolar junction transistor (BJT). (5)

7. A large wheel of radius 0.4 m and moment of inertia 1.2 kg-m2, pivoted at the center, is free to rotate without friction. A rope is wound around it and a 2-kg weight is attached to the rope. When the weight has descended 1.5 m from its starting position (a) what is its downward velocity? (b) what is the rotational velocity of the wheel? (5)

8. An electron is placed midway between two fixed charges, $q_1 = 2.5 \times 10^{-10}$ C and $q_2 = 5 \times 10^{-10}$ C. If the charges are 1 m apart, what is the velocity of the electron when it reaches a point 10 cm from q_2? (5)

9. A small particle of mass 10^{-6} gm moves along the x axis; its speed is uncertain by 10^{-6} m/sec. (a) What is the uncertainty in the x coordinate of the particle? (b) Repeat the calculation for an electron assuming that the uncertainty in its velocity is also 10^{-6} m/sec. Use the known values for electrons and Planck's constant. (5)

10. What is the probability of finding a particle in a well of width a at a position $a/4$ from the wall if $n = 1$, if $n = 2$, if $n = 3$. Use the normalized wavefunction $\psi(x,t) = \left(\frac{2}{a}\right)^{\frac{1}{2}} \sin\left(\frac{n\pi x}{a}\right) e^{\frac{iEt}{\hbar}}$. (5)

PHY.113-2075

11. Assuming that atoms in a crystal structure and arranged as close-packed spheres, what is the ratio of the volume of the atoms to the volume available for the simple cubic structure? Assume a one-atom basis. 2 (5)

12. The output of a digital circuit (y) is given by this expression:

$$y = (CB + \overline{C}A)(\overline{BA}) \quad 2$$

where A, B and C represent inputs. Draw a circuit of above equation using OR, AND and NOT gate and hence find its truth table. (5)

...ly based upon the semiconducting materials.

Semiconductor Purification: Zone Refining

Q.N;1

Silicon and Germanium are two of the most widely used semiconductor materials. Out of these two, Si has wide spread use because of various favorable factors associated with the material.

⇒ It is most abundant element after oxygen in the earth. About 27.6 % of the earth's crest is made up of silicon.

⇒ The raw material from which pure silicon is extracted is found every where in nature. So it is very cheap.

⇒ There are effective and economical crystallization methods for silicon.

⇒ It is easy for doping by impurities.

⇒ Silicon oxide is used as an excellent insulator, building layer in the MOS devices.

⇒ Silicon has efficient response to solar radiation and light.

⇒ Silicon has relatively high dielectric strength and therefore suitable for power devices.

⇒ It is non toxic. So no special care is needed when using Si for industrial and commercial applications.

⇒ The energy gap of silicon is moderate leading to small leakage current.

Silicon is generally obtained from the chemical decomposition of compounds such as SiO_2, $SiHCl_3$ and $SiCl_4$. By means of different chemical reaction the Si is chemically prepared with impurity concentration of about one part per million. The chemically purified silicon is then melted and cast into ingots. The resulting ingot is polycrystalline in nature, that is, it consists of a large number of small single crystals having random orientation with respect to one another. The required purity level in Si is achieved by a method known as zone refining discovered by the scientist William Gardner Pfann. Zone refining works on the principle that "the impurities have higher solubility in the melt as compared to that in the solid. In this process, an impure Si-ingot is taken. The rod is placed in a tubular zone refiner. Inside the refiner, an inert gas environment is maintained. A series of circular mobile heating coils are placed along the rod. The heater moves along the rod from one end to the another. At a time the heater melts the particular zone of the rod along with the impurity present there. As the heater moves, the molten part of previous zone get solidified again. During solidification, the impurity of the previous zone move to newly heated zone. In other words, as the heater shifted from one zone to another the impurity also shift to the succeeding molten zone of the ingot. By the time heater reaches to the other end of impure rod, the impurity get collected there. As the impurity prefer to remain in the melt thus could be swept to the other end of the rod. This process is repeated again and again till high purity is obtained. The other end with concentrated impurity is then cut and removed.

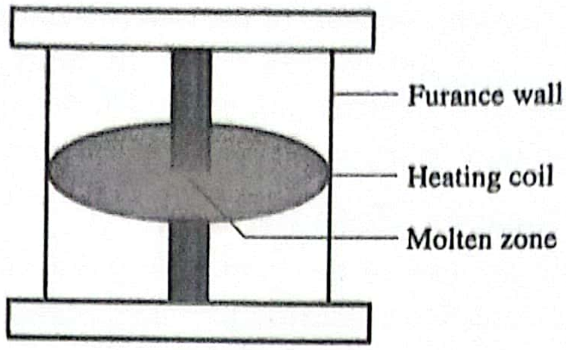

Figure: Zone Refining.

The Single Crystal Growth

To obtain the device grade silicon single crystals, the impurity concentration must be reduced. For this, the polycrystalline ingots must be transformed into the large single crystals. Nowadays, highly sophisticated IC's can be produced at reasonable cost because the methods for growing large single crystals of Si have been developed in the last few decades. Some of the methods used for single crystal growth are discussed below.

1. The Czochralski Method

The Czochralsky process is a method of crystal growth used to obtain single crystal of semiconductors. A Silicon wafer is a thin piece of semiconductor material which is used in fabrication process in integrated circuits. The following is the summary of steps in Czochralski process of Silicon wafer manufacturing:

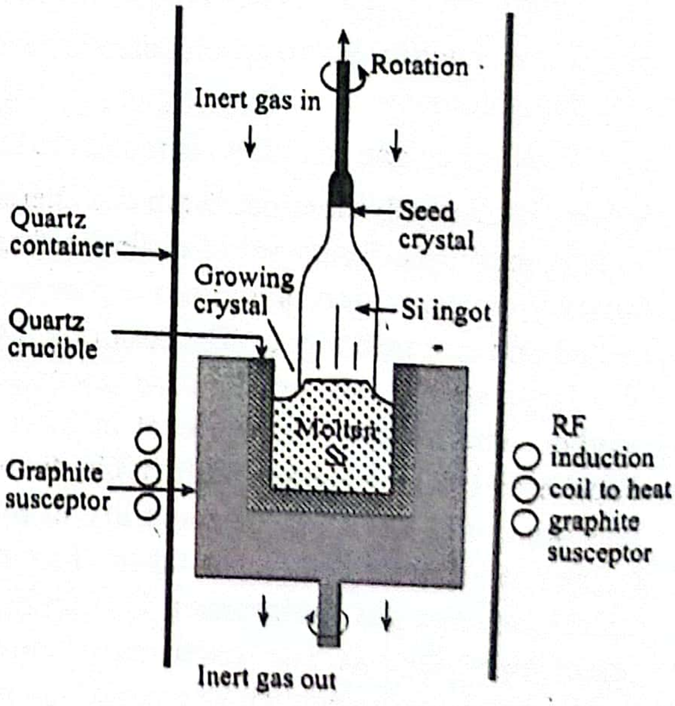

Figure: Single crystal growth by Czochralski method

a. **Preparation of high purity of molten silicon**

In this process high purity of silicon is encouraged to be used as molten form to form the single crystal Silicon. SiO_2 can be used to prepare high purity molten Silicon. Then the substance will be heated to its melting point into a crucible (pot) made of quartz. The supersaturated molten silicon will become the source of silicon wafer.

b. **Dipping the seed crystal**

A small piece of single crystal material known as seed crystal will be dipped into the saturated molten silicon solution. Seed crystal is equipment used to grow a large crystal of same material. The large crystal will grow when the seed crystal dipped into the melt will then be cooled.

c. **Pulling the seed upward**

The seed will extract from the molten silicon pool and rod will be pulled upward and rotated at the same time. During this time the rod and crucible rotated in opposite direction to minimize the effect of contraction in the melt. In manufacturing single crystal silicon, the temperature gradient, pulling rate and rotation speed influences the size of crystal. As the seed crystal is slowly raised upward, the molten silicon will solidifies as same as the seed. This is why this process is called growing which is producing a new crystal of silicon from molten silicon. The large cylindrical crystal silicon is called ingot which can be grown 300mm to 400 mm in diameter.

2. The Bridgman-Stockbarger Method

This method is named after physicists Percy Williams Bridgman and Donald C. Stockbarger. It involves mainly the three steps.

(a) Sealing the starting material in a crucible

(b) Melting

(c) Crystal growth by passing the crucible through the temperature gradient zone.

The material is placed in a crucible having a conical tip. The sample which is initially polycrystalline is first melted in an upper furnace that is maintained a few degrees above the melting point. The melt with crucible is moved down where it gets slowly cooled into the lower furnace with a temperature a few degree below the melting point. While lowering the crucible, it is rotated simultaneously to stir the melt. A small crystal is formed at the tip of the crucible. This crystal acts then as the seed for the rest of the melt and, as the crucible continues to be lowered, a single crystal is grown.

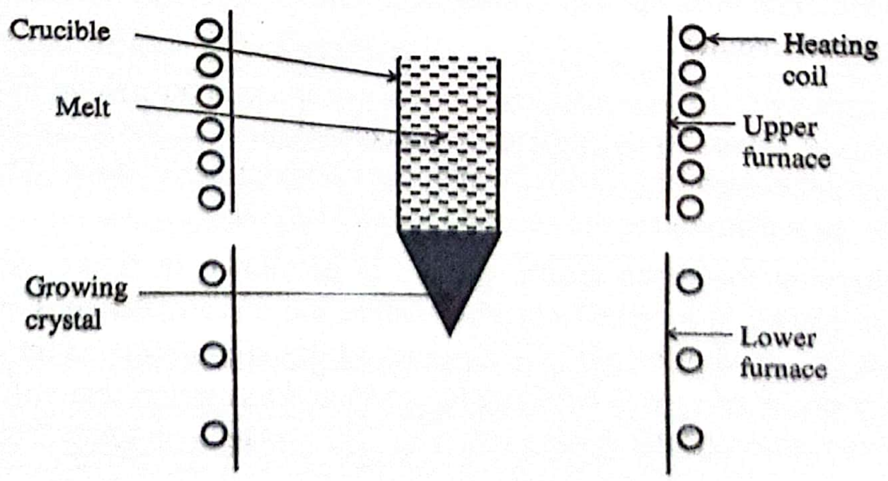

Figure: Single crystal growth by Bridgman-Stockbarger method

3. Floating Zone Method

The two methods just described have the disadvantages that the melt tends to dissolve some of the oxygen from the walls of the crucible (usually made of Silica, SiO_2). The problem is solved in floating zone method which provides with the crucible altogether.

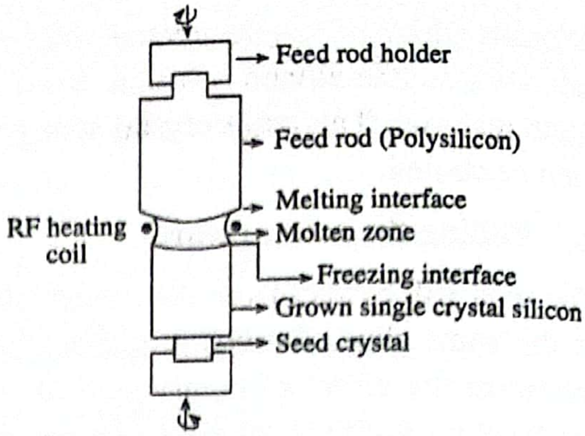

Figure : Floating zone method of crystal growing

The Float Zone method is based on the zone melting process as shown in figure. The production takes place under vacuum or in an inert gas medium. The process starts with a high purity polycrystalline rod of raw material and monocrystalline (single crystal) seed crystal that are held face to face in a vertical position and are rotated with a radio frequency (R.F.) heating coil. Both are partially melted.

As the molten zone is moved along the polycrystalline rod the molten silicon solidifies into a single crystal and simultaneously, the material is purified. Most impurities are more soluble in melt than in the crystal. A seed crystal is used at one end in order to start growth. The impurities can be removed as they prefer to go to the liquid phase. The diameter of Float Zone wafer (wafer: a round thin piece) are generally not greater than 150 mm due to the surface tension limitation during growth.

The basic feature of this growth technique is that the molten part of the sample is supported by the solid part. After the heating coils move over the whole polysilicon rod, it converts to a single crystal silicon ingot.

4. Epitaxy

Epitaxy refers to the deposition of a crystalline over layer on a crystalline substrate. The over layer is called an epitaxial film or epitaxial layer. If the over layer either forms a random orientation with respect to the substrate or does not form an ordered over layer, it is termed as non epitaxial growth. The term epitaxy comes from Greek roots 'epi' meaning 'above' and taxis meaning 'an ordered manner'.

a. In vapor phase epitaxy (VPE) atoms of Si from a vapor are deposited on the substrate in a layer that has the same crystal structure and orientation as the substrate. Thus the substrate serves as the seed crystal into which the epitaxial layer grows. This first layer in turn serves as the substrate for the second layer and so on.

   A schematic diagram for vapor phase epitaxy is as shown in figure. Single crystal wafers of Si are placed in a heated chamber called the reacter. Gaseous compound of silicon ($SiCl_4$) together with the appropriate reactant gas are introduced into the reactor. The temperature of the reactor is adjusted to produce the reaction that will liberate the silicon by decomposition of the compound. Thus for example at 1250°C the following reaction occurs.

$SiCl_4 + H_2 \rightarrow Si + HCl$

Some of the Si atoms released in the reaction are deposited on the substrates, thereby forming epitaxial layers. If the chemicals used for the reaction are of high purity, the epitaxial layer of Si will be highly pure.

The Silicon VPE may also use pyrolytic (Pyrolytic: Chemical change because of heat) decomposition of silane.

$$SiH_4 \xrightarrow{650^\circ C} Si + 2H_2$$

This reaction is not reversible and takes place at lower temperature.

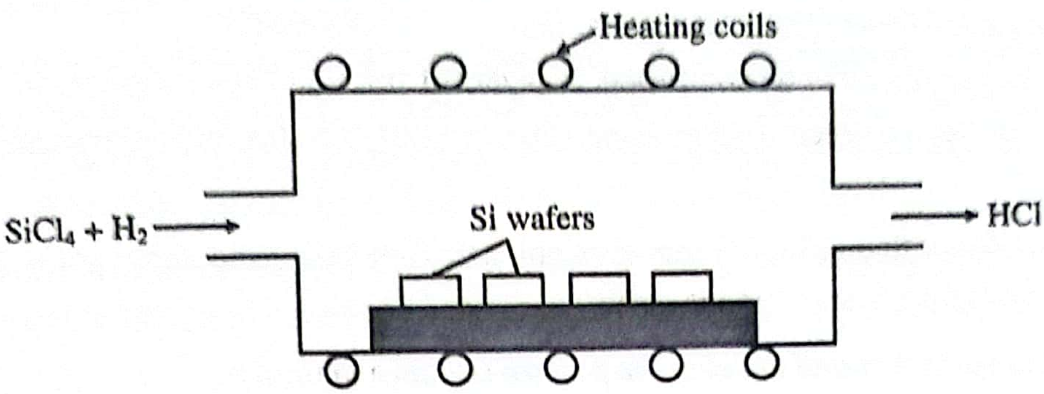

Figure: Vapor phase epitaxy.

b. In liquid phase epitaxy (LPE), the substrate is dissolved into the melt of the material to be deposited. This happens at temperature well below the melting point of the substrate material. The substrate acts as a seed for material crystallizing directly from the melt.

c. Solid phase epitaxy (SPE) is usually done by first depositing a film of amorphous material on a crystalline substrate. The substrate is then heated to crystallize the film.

d. In molecular beam epitaxy (MBE), a source material is heated to produce an evaporated beam of particles. These particles travel through a very high vaccum to the substrate where they condense. Substrate temperature during this process ranges from 400 - 900°C.

The Process of IC Production

The first process involved in the fabrication of integrate circuit is photolithography which includes epitaxial growth, oxidation, oxide removal and pattern definition. The photolithography is followed by doping (introduction of selective impurities in Si) and metallization (Interconnection of components).

1. Photolithography

It is the process which involves photographic transfer of a pattern to the surface of wafer to make diffusion window by etching. In this process a geometrical pattern is transferred from a mask to the surface of silicon wafer. Lithography literally means "Writing on stone". Photolithography involves following steps.

Step i: *Coat Si with oxide then with photoresist (Oxidation)*

At first the Silicon single crystal is oxidized in an oxidation furnace to form a thin layer of SiO_2, which is excellent barrier against diffusion. The oxide layer is grown by heating the silicon wafer to temperatures ranging between 1000°C and 1200°C in an atmosphere of either pure oxygen or steam. The thickness of the oxide layer depends on the oxidation time and the temperature and the composition of the atmosphere in which the oxidation is performed. By careful selection of these three parameters, the exact thickness of the layer can be controlled. A layer 0.1 μm thick can be grown in one hour at T = 1000°C, in pure oxygen. In the same time, a layer 0.5 μm thick grows in a steam environment.

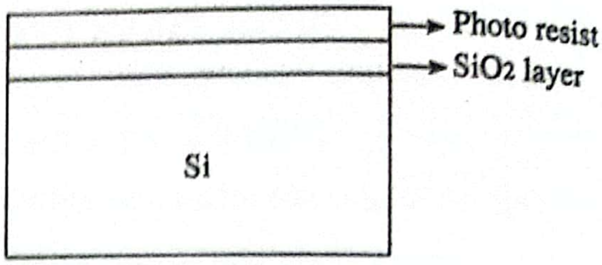

Figure (1)

Again coat the wafer with a radiation sensitive polymer film called the photo resist. Spin the silicon wafer very fast so that coating is uniform (figure 1).

Step ii: *Expose to radiation and develop the pattern (Pattern definition)*

Allow the UV radiation to fall on photo resist through mask. A mask is a glass plate with transparent and opaque regions made on it. Only those regions of the mask which are transparent allow the radiation to fall on the semiconductor. Only those portions which are exposed to radiation, their properties are going to change. The photo resists from the exposed regions are removed. Now the mask pattern is transferred to top of wafer. (Figure 2)

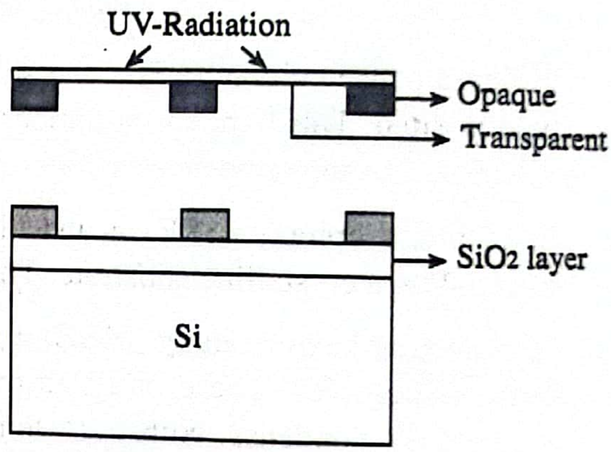

Figure (2)

Step iii: *Oxide removal*

Now the substance is kept in diluted etching solution (hydro fluoric acid, HF), the SiO_2 from the Si regions corresponding to transparency of mask is removed. (Figure 3)

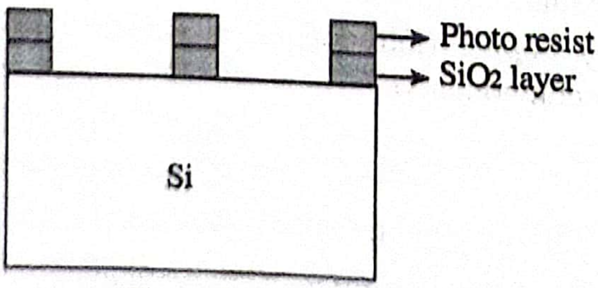

Figure (3)

Step iv: All the photoresist is removed by keeping it on photoresist remover solution (Figure 4).

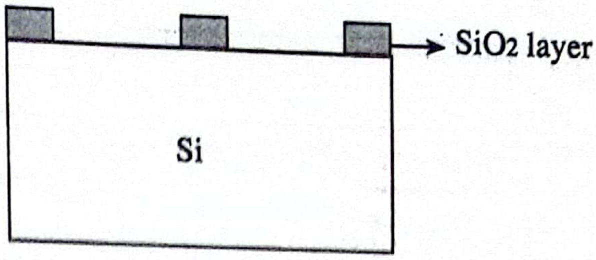

Figure (4)

Compare the pattern on mask with pattern of SiO_2 on the top of Si wafer, the opaque regions on the mask have corresponding pattern of SiO_2 on Si wafer. The regions corresponding to transparency of mask have no oxide. These are the regions where the dopant will be incorporated. This process in which UV light is used to produce the diffusion window pattern is called *Photolithography*.

The pattern on the mask and wafer are identical. Those pattern obtained on wafer are said to be due to positive photoresist. A positive resist is one which gets soften when exposed to radiation. If the photoresist is hard, the complement pattern is obtained with semiconductor regions etched with UV radiation. It is called a negative photo resist.

(Note: SiO_2 is an excellent insulating material. It has good masking properties. The region which is not to be doped is masked with SiO_2. It does not allow dopant to pass through it.)

2. Doping

An integrated circuit has informal name chip. The formation of circuit components in a chip is achieved by the selective introduction of donor and acceptor impurities into the Si wafer to create localized n-type and p-type regions. The two most commonly used techniques for doping are diffusion and ion implantation.

a. Diffusion

When Si is heated to temperatures in the range of 1000°C, some of the semiconductor atoms move out of their lattice sites, leaving behind empty lattice sites that can migrate through the sample. If the heating is done in an atmosphere of either acceptors or donors, these impurity atoms move into the vacant lattice sites formed at high temperature. The diffusion of the dopant impurities can be stopped by cooling down the wafer. Because the diffusion of impurities is time and temperature dependent, the depth of the diffusion layer can be controlled by varying these two parameters. The SiO_2 pattern, formed by photolithography acts as a mask that permits the diffusion of the impurities only in specific regions of the wafer.

The open furnace tube system using solid, liquid and gaseous dopant sources is the most common diffusion technology used in IC fabrication. The wafers are loaded vertically into a quartz boat and put into the furnace where the wafers are heated to high temperature. In general, diffusion systems are similar to oxidation furnace.

(i) **Solid Source:** In this system, the dopant source is in solid form as shown in figure (1). The carrier gases N_2 or O_2 picks up the vapour from the dopant source and transport it to the furnace tube, where the dopant atoms are deposited on the surface of wafer.

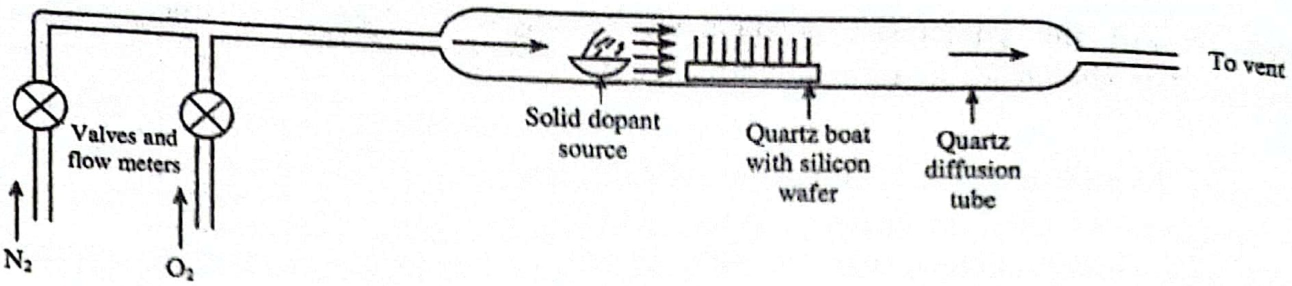

Figure (1): Open furnace tube diffusion system: Solid impurity source

The common solid source of Boron is Trimethyl Borate (TMB)

$$2\,(CH_3O)_3\,B + 9O_2 \xrightarrow{900^0 C} B_2O_3 + 6CO_2 + 9\,(H_2O)$$

$$2\,B_2O_3 + 3Si \leftrightarrow 4B + 3\,SiO_2$$

The common solid source of Phosphorous is Phosphorous Pentaoxide.

$$2P_2O_5 + 5\,Si \leftrightarrow 4P + 5\,Si\,O_2$$

(ii) Liquid Source

In this system the dopant source is in liquid form as shown in figure (2). The carrier gas passes through a bubbler where it picks up the vapour of the liquid source. The carrier gas carries the vapour into the furnace tube where it reacts with the surface of the silicon wafer.

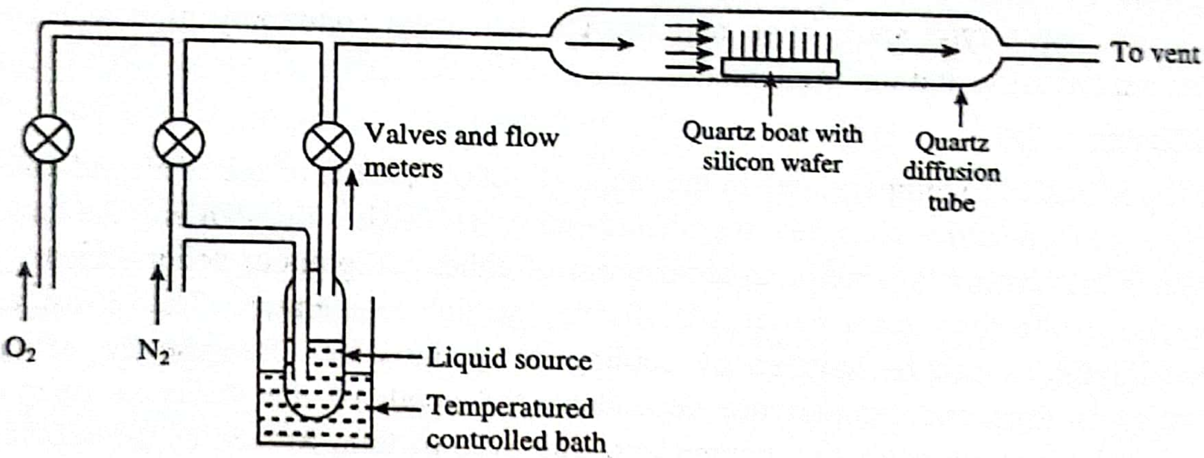

Figure (2): Open furnace tube diffusion system: Liquid impurity source

The most common liquid source of Boron is Boron Tribromide.

The reaction is

$$4\,BBr_3 + 3O_2 \rightarrow 2B_2\,O_3 + 6\,Br_2$$

$$2\,B_2O_3 + 3Si \leftrightarrow 4B + 3\,SiO_2$$

The common liquid source of 'P' is Phosphorous Oxychloride.

$$4\,P\,O\,Cl_3 + 3\,O_2 \rightarrow 2P_2O_5 + 6Cl_2$$

$$2\,P_2O_5 + 5Si \leftrightarrow 4P + 5SiO_2$$

Electronic Component Fabrication of a Chip

In this section we will discuss how the techniques just described can be used to fabricate the basic components of a circuit such as transistors, diodes, resistors and capacitors. In the actual fabrication of an IC, parts of several components are formed simultaneously. This will be illustrated at the end of this section, where we discuss how a simple NOR gate can be made.

1. Transistor and Diodes

The fabrication of IC is done plane by plane at one surface of the wafer so that the deepest region tends to be fabricated first. We will consider fabrication of a npn bipolar junction transistor. The fabrication follows following steps.

1. We start with a p-type single crystal of thickness about 200 µm, oriented {1, 1, 1} and with a resistivity of 10Ω-cm.

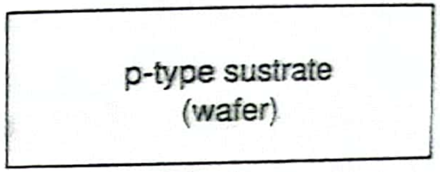

Figure (1)

2. Grow an n-type epilayer on the top of wafer by epitaxy [epitaxy - arranged upon]. The epitaxial layer is very much thinner to the original layer of bulk. This grown epitaxial layer is going to be collector of npn transistor.

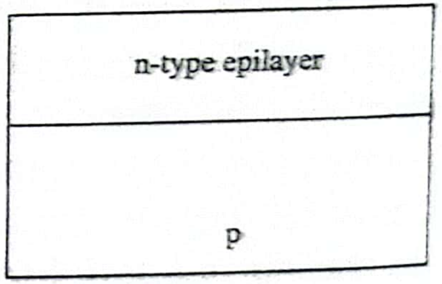

Figure 2

3. Now doping acceptors over n-region to form p-region for base diffusion [after photolithography] (figure 3)

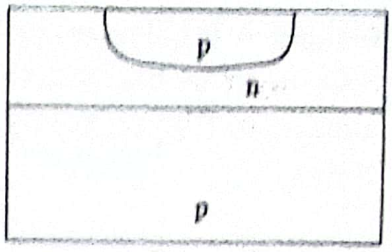

Figure 3

4. Again dop donors to form emitter. (After photolithography)

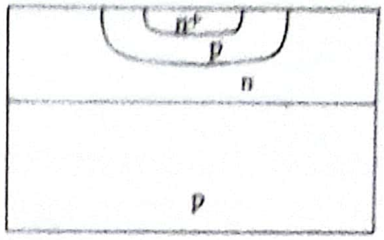

Figure 4

5. Metallization involves deposition of metal (mostly aluminum) elements over base, collector and emitter region (After photolithography) for electrical connection. Remove all oxide layer (used in photolithography) and unwanted metal deposition by etching. Thus fabricated 'npn' transistor can be used after electrically tested.

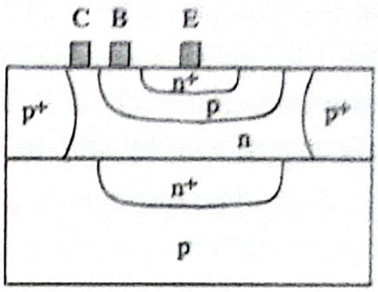

Figure 5

The steps needed to build a diode are identical to those used in the fabrication of a transistor except that the last diffusion of donor impurities (step 4) is omitted.

Note: Doping can be done either by diffusion or by Ion Implantation method.

2. Resistors

In integrated circuit, resistor can be made by the shallow diffusion of a p-type channel into an n-type region (or vice versa). The current is forced to flow through the p-type channel by maintaining the channel at a negative voltage with respect to the surrounding n-type region. (See figure in the fabrication of NOR gate). The resistance of the channel will be determined by its length, its cross section, as well as the doping concentration. Because of its relatively high conductivity, Si is not a useful material for a resistor. As a result, it is difficult to obtain large resistance values in IC's without using too much space in the chip. In such cases where large resistors are needed, one standard approach is direct substitution. Since transistor used in the common emitter configuration can be considered as a base current-controlled resistor. Thus a transistor can be introduced in a circuit where a resistor is needed. The effective resistance between the collector and the emitter will be determined by the base current.

Set of Differential equation of the oscillation of horizontal spring by application of Hook's Law and Newton's Law. Write its solution. Also find acceleration, time period and velocity.

⇒ Q.N;2

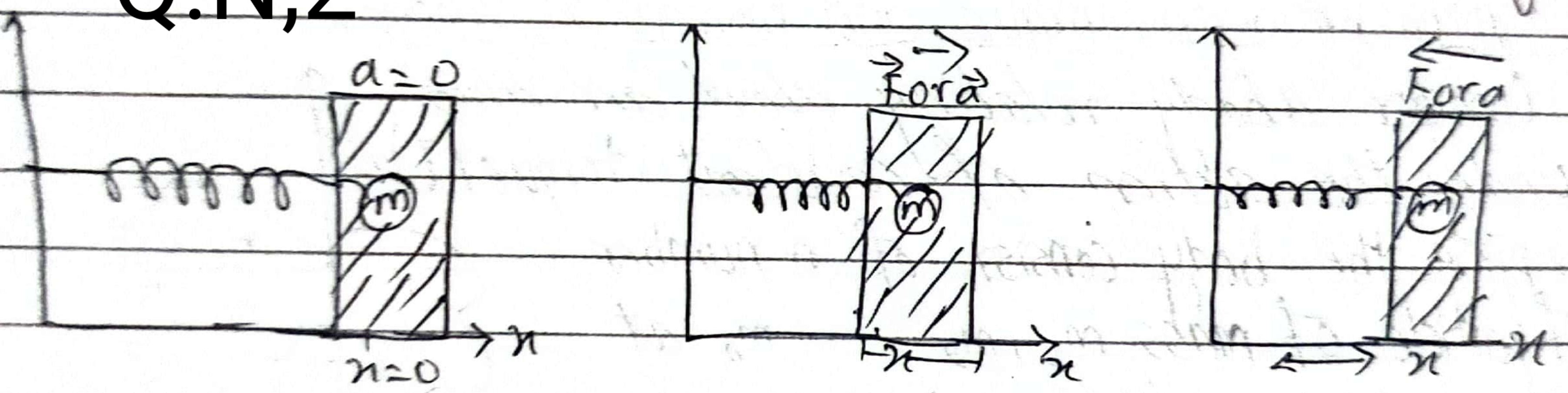

Fig:- motion of horizontal spring along x-axis

Let m be the mass of the particle which is attached by horizontal spring. At first it is rest $(a=0)$ after application of force it stretched then Force $F = kx$ --- (i)
which is given by Hook's Law, where x is the stretching length. When we apply Force in one direction then there is reaction Force in another direction with the help of Newton's third law of motion so Force becomes:

$$F = -kx \quad \text{--- (ii)}$$

where K is Force constant or spring constant

$$F = ma$$

$$F = m\frac{d^2x}{dt^2} \quad \text{--- (iii)}$$ (double derivative of velocity)

From eqⁿ (ii) and (iii)

$$m\frac{d^2x}{dt^2} = -kx$$

$$\boxed{m\frac{d^2x}{dt^2} + kx = 0} \quad \text{--- (iv)}$$

which is the eqⁿ of horizontal spring. This eqⁿ is same as the eqⁿ of S.H.M so, it is oscillatory motion.

Solution of this equation is

$$x = A\sin(\omega t + \phi)$$

wher ϕ is the phase angle, $(\omega t + \phi)$ is phase Factor and A is Amplitude.

using relation,

$$ma = -kx$$

$$a = \frac{-k}{m}x$$

$$\therefore \boxed{\text{acceleration } (a) = -\frac{k}{m} \times x}$$

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Again, From acceleration of oscillatory motion

$$a = -\omega^2 x$$

$$\cancel{-}\frac{k}{m} \times \cancel{x} = \cancel{-}\omega^2 \cancel{x}$$

$$\omega = \sqrt{\frac{k}{m}}$$

$\therefore$ $\boxed{\text{angular velocity } (\omega) = \sqrt{\frac{k}{m}}}$

$\boxed{\text{velocity}(v) \sqrt{\frac{k}{m}} \times x}$ $(v = \omega r)$

Time period,

$$T = \frac{2\pi}{\omega}$$

The time taken by particle to complete a cycle of oscillation is called time period 'T'

or, $$T = \frac{2\pi}{\sqrt{\frac{k}{m}}}$$

$\therefore$ $$\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$$

Frequency,

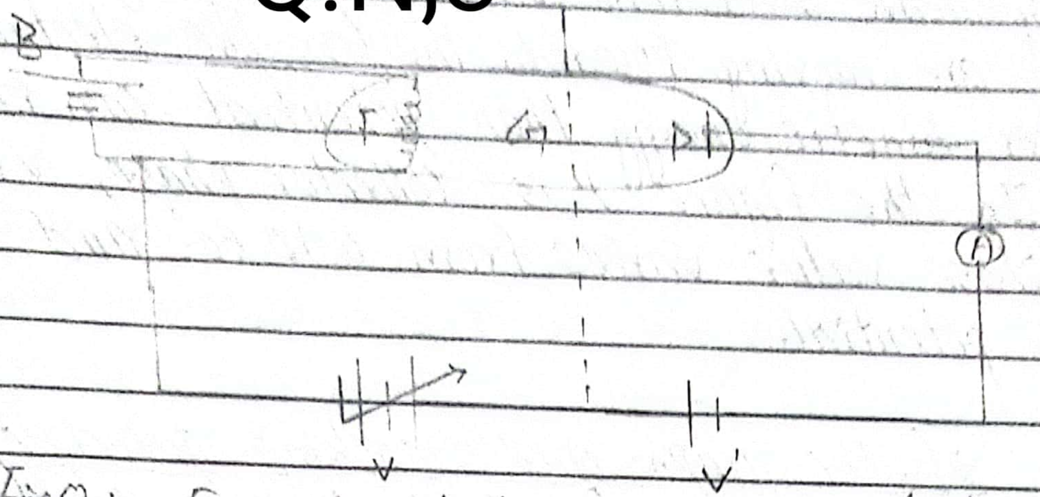
$$F = \frac{1}{T}$$

The number of complete oscillations made by an ocillating particle in one second is called frequency. It is given by $F = \frac{1}{T}$

or, $$F = \frac{1}{2\pi\sqrt{\frac{m}{k}}}$$

$\therefore$ $$\boxed{F = \frac{1}{2\pi}\sqrt{\frac{k}{m}}}$$

State Franck-Hertz Experiment and Explain his experiment. Q.N;3



Fig(i):- Experimental arrangement of franck-Hertz experiment

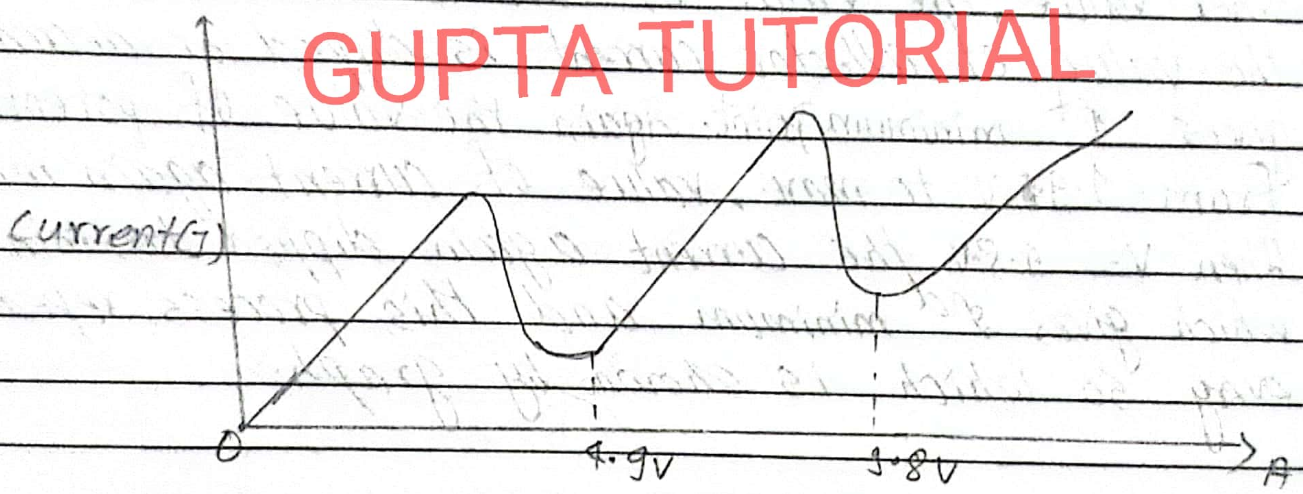


fig:(ii) Accelerating potential V

Statement :-

He proved that the existence of discrete energy state is as atom and studied the Ionization and excitation of mercury, Helium and Neon atom. He found that the discrete energy states of atoms are quantised in nature

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Explaination

The experiment arrangement of franck - Hertz Experiment is as shown in above figure ①. Gas is filled in the mercury Table. Electrons are produced by a filament F which are moving towards the G. The electrons which have greater kinetic energy than potential can reach from G to P. In the figure P is collector phase, V is variable potential whose value varies from 0 to 60. and V' is the fixed potential.

Explaination of the graph and working principle

When the value of potential increases from 0 to other value, ~~the~~ value of current also increase. At V = 4.9V the value of collector current is dipped or decreases. It gives 1st minimum point. Again the value of potential increase from 4.9 V to max, value of current again increases. When V = 9.8V the current again dipped to minimum which gives 2nd minimum and this process repeated every so which is shown by graph.

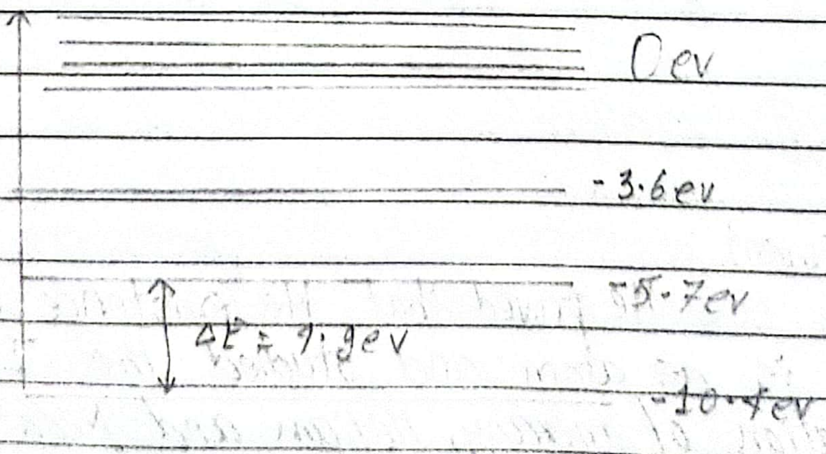

Fig. ③ Atomic energy levels of mercury atom

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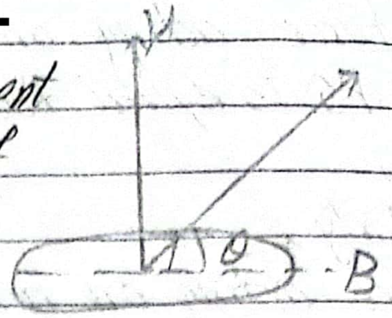
Let electrons are going from G to P. At that time electrons gets energy. At V=4.9V, the electrons acquires 4.9ev energy. It looses this energy when strike with mercury atom with inelastic collision. At that the current decreases and give minimum value. This suggest that the current is not becomes 0 which means some electrons can reache the plate P without loss of energy. After this minimum point the electron again moves and starts to reach to the plate. The value of potential increases and value of current also increase. The value of potential V=9.8V the current dipped and gives 2nd minimum point the electron again strike with the mercury atom of Inelastic collision. At that situation, the atom gets energy 4.9ev and emit photon in energy collision. The wavelength of the photon coming from the tube is 2536A° which is found by Franck Hertz on his experiment. Hence we can find the energy of Photon.

$$E = \frac{hc}{\lambda} = \frac{(6.61 \times 10^{-34} \times 3 \times 10^{8})}{(2536 \times 10^{-10})} = 4.9ev$$

The leaving energy of electron when strike with mercury atom is same as the energy of photon found by the experiment. This shows that the existance of discrete energy states is as atom is proved.

Magnetic dipole moment Q.N;4



The magnetic dipole moment (μ) is defined as the product of the current through the loop and area of the loop which is given by

$$\mu = IA$$

The torque acting on the loop due to magnetic field intensity (B) is

$$\tau = BIA\sin\theta$$

$$\tau = \mu B\sin\theta \quad (\mu = IA)$$

The energy of the dipole is defined as the work done in changing its orientation from 90° to θ° is

$$E = \int_{90}^{\theta} \tau \, d\theta$$

$$E = \int_{90}^{\theta} \mu B\sin\theta \, d\theta$$

$$E = -\mu B\left[\cos\theta\right]_{90^\circ}^{\theta}$$

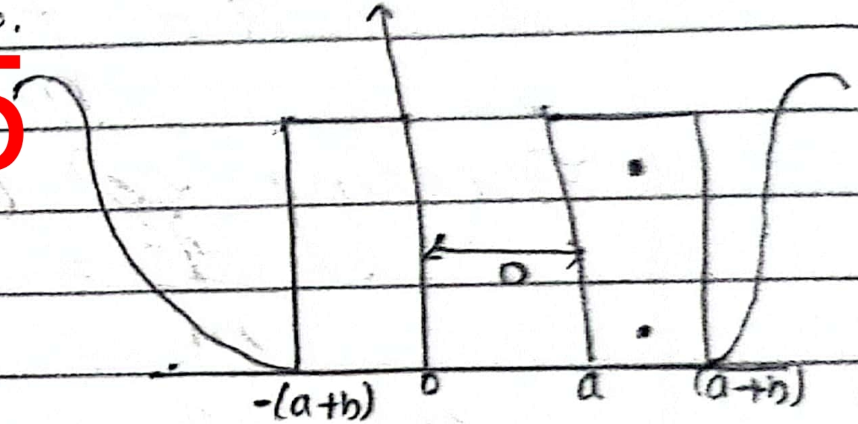
$$\boxed{E = -\mu B\cos\theta}$$

$$\boxed{E = -\vec{\mu}\cdot\vec{B}}$$ in vector form

Kroning-Denny Model

It assume that the potential energy of an electron in a linear array of positive nuclei has the force of periodic array of square.

Q.N;5



The potential energy is given by

$$V(x) = 0 \quad \text{for } 0 \le x \le a$$
$$= V_0 \quad \text{for } -b \le x \le 0$$

The schrodinger wave equation is

$$-\frac{\hbar^2}{2m} * \frac{\delta \psi}{\delta x^2} + V(x)\,\psi(x) = E\psi(x) \quad ---- \quad (1)$$

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In region $0 \leq x \leq a$

$$\frac{d^2\psi}{dx^2} + \frac{2mE}{\hbar^2}\psi_1(x) = 0$$

$$\frac{d^2\psi}{dx^2} + \alpha^2\psi_1(x) = 0 \quad \text{———— (2)}$$

In region $-b \leq x \leq 0$

$$\frac{d^2\psi_2}{dx^2} - \frac{2m}{\hbar^2}(V_0 - E)\psi_2(x) = 0$$

$$\frac{d^2\psi_2}{dx^2} - \beta^2(\psi)(x) = 0 \quad \text{———— (3)}$$

Sol^n of eq^n (2),

$$\psi_1(x) = Ae^{i\alpha x} + Be^{-i\alpha x} \quad \text{———— (4)}$$

Where,

$$\alpha^2 = \frac{2mE}{\hbar^2} \quad ; \quad \beta = \frac{2m(V_0 - E)}{\hbar}$$

Sol^n of eq^n (3),

$$\psi_2(x) = Ce^{\beta x} + De^{-\beta x} \quad \text{———— (5)}$$

Since, the periodic pot^n the wave fx^n is given by Bloch eq^n,

$$\psi(x) = U_k(x)e^{ikx} \quad \text{———— (6)}$$

The sol^n of region $a \leq x \leq a+b$ is related with sol^n (5),

$$\psi_3(a \leq x \leq a+b) = \psi_2(-b \leq x \leq 0)$$

$$\psi_3(x) = (Ce^{\beta x} + De^{-\beta x})e^{ik(a+b)} \quad \text{———— (7)}$$

Applying boundary cond^n at $x = 0$,

let, $x = 0$

$$\psi_1(0) = \psi_2(0)$$

$$\psi_1'(0) = \psi_2'(0)$$

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From eqⁿ (4) & (5),

$$A+B = C+D \quad \text{—— (8)}$$

i.e $$(A-B) = \beta(C-D) \quad \text{—— (9)}$$

Again,

at $x=0$, $\psi_1(a) = \psi_3(-b)$

$\psi_1'(a) = \psi_3'(-b)$

From eqⁿ (4) & (7),

$$Ae^{i\alpha a} + Be^{-i\alpha a} = \left(Ce^{-\beta b} + De^{\beta b}\right)e^{ik(a+b)} \quad \text{—— (10)}$$

$$i\alpha\left(Ae^{i\alpha a} - Be^{-i\alpha a}\right) = \beta\left(-Ce^{-\beta b} + De^{\beta b}\right)e^{ik(a+b)} \quad \text{—— (11)}$$

The solⁿ of these eqⁿ is given by,

$$\begin{vmatrix} 1 & 1 & -1 & -1 \\ i\alpha & -1 & -\beta & \beta \\ e^{i\alpha a} & e^{-i\alpha a} & e^{-\beta b}\cdot e^{ik(a+b)} & -e^{\beta b}\cdot e^{ik(a+b)} \\ i\alpha e^{i\alpha a} & -i\alpha e^{i\alpha a} & -\beta e^{-\beta b}\cdot e^{ik(a+b)} & \beta e^{\beta b}\cdot e^{ik(a+b)} \end{vmatrix} = 0$$

By solving,

$$\frac{\beta^2-\alpha^2}{2\alpha\beta}\sinh\beta b\sin\alpha a + \cosh\beta b\cdot\cos\alpha a = \cos k(a+b)$$

Put, $\beta >>> \alpha$ & $b \to 0$

$$\frac{\beta^2}{2\alpha\beta}\beta b\sin\alpha a + 1\cdot\cos\alpha a = \cos ka \quad \text{—— (12)}$$

$$\frac{\beta^2 ab}{2\alpha a}\sin\alpha a + \cos\alpha a = \cos ka$$

Let, $P = \dfrac{\beta^2 ab}{2}$ so that,

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$$\frac{P}{\alpha a} \sin \alpha a + \cos \alpha a = \cos ka \longrightarrow (13)$$

The physical significance of P is that if P is increased, electron is bound strongly.

When $P \rightarrow 0$, potn barrier becomes weak, thus eqn (13) $P \rightarrow 0$

$$\cos \alpha a = \cos ka$$

$$\therefore \alpha = k$$

SBS,

$$\alpha^2 = k^2$$

$$k^2 = \frac{2mE}{\hbar^2}$$

$$\Rightarrow E = \frac{\hbar^2 k^2}{2m} \longrightarrow \text{This is the req exp}^n$$

Eqn (13) gives the condn which must be satisfied so that soln of wave eqn may exist. The value of cos ka lies "+1" to "-1".

Bipolar Junction Transistor "BJT" Q.N;6

A P-N junction ~~affects~~ offers a low resistance under Forward bias and high resistance offered under reverse bias. A single crystal having two close P-N Junction may be prepared. One Junction being Forward bias and other Junction being reversed bias. Then one Junction will offer Low resistance and other will offer high resistance. A small ~~sin~~ signal is applied across forward bias, it ~~is~~ will apper high resistance Junction in reversed bias with high power gain. Such a device is called transistor. The point transistor have number of Limitations to solve these difficulties Junction transistor is inverted. The transistor is a electronic device formed by the combination of two P-N Junction in a specific manner

There are two types of transistor
① P-N-P ② N-P-N

① P-N-P Transistor

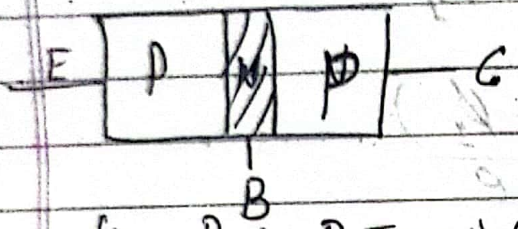


fig:- P-N-P Transistor

(ii) N-P-N Transistor

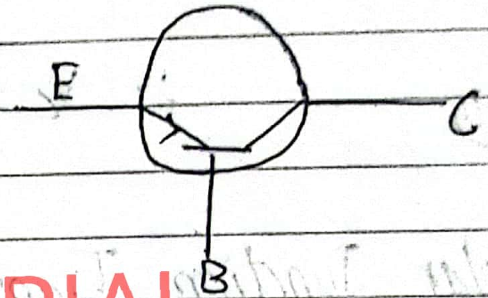
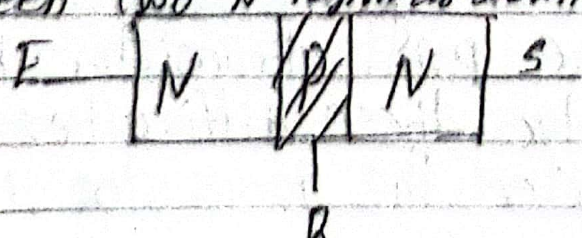


fig:- Symbol of N-P-N Transistor

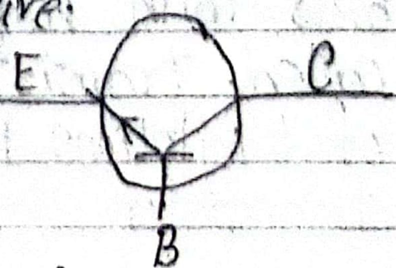
It consists of silicon or Germanium crystal in which thin Layer of N region is in between two P-region. Arrow is symbol of P-N-P transistor from emitter to base

② N-P-N Transistor

It consists of silicon or Germanium crystal in which a thin layer of P-region is in between two N-region as shown in figure.



fig(a) N-P-N Junction



fig(b) N-P-N Transistor

A large wheel of radius 0.4m and moment of inertia $1.2 kgm^2$, pivoted at the centre is free to rotate without friction. A rope is wound it and a 2kg weight is attached to the rope. When the weight has descended 1.5m from its starting position

Q.N;7

(a) What is its downward velocity?

(b) What is the rotational velocity of wheel?

Given,

radius $(r) = 0.4m$

Moment of inertia $(I) = 1.2 kgm^2$

mass $(m) = 2kg$

height $(h) = 1.5m$

velocity$(v) = ?$

(a) From conservation of energy,

P.E of weight = K.E of weight + Rotational K.E of wheel

or, $mgh = \frac{1}{2} mv^2 + \frac{1}{2} I\omega^2$

or, $2mgh = mv^2 + I\omega^2$

or, $2mgh = mv^2 + I\frac{v^2}{r^2}$ $\quad (\omega = \frac{v}{r})$

or, $2mgh = v^2\left(m + \frac{I}{r^2}\right)$

or, $v^2 = \frac{2mgh}{m + I/r^2}$

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or, $v = \sqrt{\frac{2mgh}{m + I/r^2}} = \sqrt{\frac{2 \times 2 \times 9.8 \times 1.5}{2 + \frac{(1.2)}{(0.4)^2}}}$

$\therefore v = 2.5 m/sec$

(b) we have,

velocity of wheel $(v) = 2.5 m/sec$

since,

$v = r\omega$

$\omega = \frac{v}{r} = \frac{2.5}{0.4} = 6.2 rad/sec.$

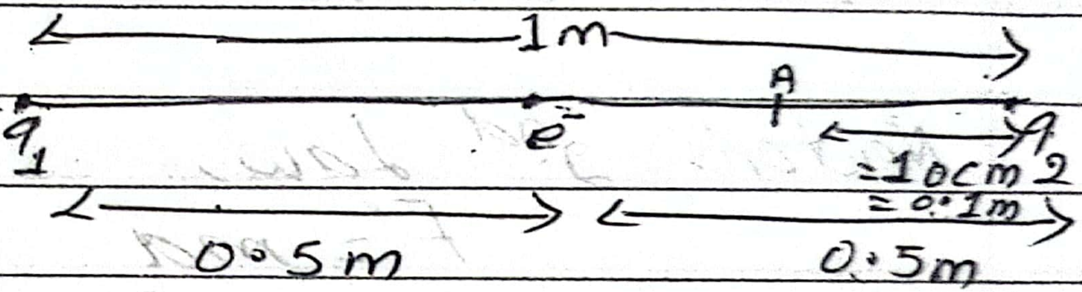
CamScanner

An electron is placed midway between two fix charge $q_1 = 2.5\times10^{-10}C$ and $q_2 = 5\times10^{-10}C$. If the charge are 1m apart what is the velocity of electron when it reaches a point 10cm from q_2.

Q.N;8

Distance travelled by electron $= 0.5 - 0.1$

$= 0.4m$



Distance between q_1 and $q_2 = 1m$

Distance between e and $q_1, q_2 = 0.5\,m = r_1 = r_2$

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Distance travelled by e^- towards q_2 from initial Position $= 0.5 - 0.1 = 0.4m$

Using eqn of motion,

$$v^2 = u^2 + 2as \quad (u=0)$$

$$\therefore \quad v = \sqrt{2as}$$

The electrostatics force between q_1 and e^- is

$$F_1 = \frac{q_1 e}{4\pi\varepsilon_0 r_1^2}$$

The electrostatics force between q_2 and e^- is

$$F_2 = \frac{q_2 e}{4\pi\varepsilon_0 r_2^2}$$

Net force

$$F = F_2 - F_1$$

$$F = \frac{e}{4\pi\varepsilon_0}\left[\frac{q_2}{r_2^2} - \frac{q_1}{r_1^2}\right]$$

$$F = 1.6\times10^{-19} \times 9\times10^{9} \left[\frac{5\times10^{-10} - 2.5\times10^{-10}}{(0.5)^2}\right]$$

$$F = 1.44\times10^{-18} N$$

Newton's 2nd Law,

$$F = ma$$

$$a = \frac{F}{m} = \frac{1.44\times10^{-18}}{9.1\times10^{-31}} = 1.58\times10^{12} m/s^2$$

Now,

$$\text{velocity}(v) = \sqrt{2\times1.58\times10^{12}\times0.4}$$

$$v = 1.125\times10^{6} m/s$$

A small particles of mass 10^{-6} g moves along x-axis its speed is Uncertain by 10^{-6} m/s. Q.N;9

ⓐ What is the uncertainty in the x-co-ordinate of the particle?

ⓑ Repeat the calculation for an electron assume that the uncertainty in its velocity is about 10^{-6} m/s

Sol) Here,

mass (m) = 10^{-6} g = $10^{-6} \times 10^{-3}$ = 10^{-9} kg

velocity in Uncertain (Δv) = 10^{-6} m/s

Uncertainity in x-co-ordinate of the particle (Δx) = ?

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we know that,

from Heisenberg uncertainty principle

$$\Delta x \cdot \Delta p \geq h$$

$$\Delta x \cdot \Delta p \geq \frac{h}{2\pi}$$

(c) $$\Delta x \cdot \Delta p = \frac{h}{2\pi}$$

or, $$\Delta x = \frac{h}{2\pi \Delta p}$$

$$\therefore \Delta x = \frac{h}{2\pi m \Delta v} = \frac{6.62 \times 10^{-34}}{2\pi \times 10^{-3} \times 10^{-6}} = 1.05 \times 10^{-19} m$$

(b) I^{st} and 2^{nd} question is same only change in mass we take mass of electron in place of mass of particle.

we have,

$$m_e = 9.1 \times 10^{-31} kg$$

so that

$$\Delta x = \frac{h}{2\pi m \Delta v} = \frac{(6.62 \times 10^{-34})}{(2\pi \times 9.1 \times 10^{-31} \times 10^{-6})} = 116 m$$

What is the probability of finding a particle in a well of width "a" at a position $\frac{a}{4}$ from the well if $n=1$, $n=2$, $n=3$ use normalized wave function ~~$\psi(x,t)=\sqrt{\frac{2}{a}}\sin\frac{n\pi x}{L}$~~

$$\psi(x,t)=\sqrt{\frac{2}{a}}\sin\frac{n\pi x}{L}\, e^{\frac{-iEt}{\hbar}} \quad \text{(1)}$$

Q.N;10

a) width of wall(L) = a

position (x) = $\frac{a}{4}$

Normalised wave function

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$$\psi(x,t) = \sqrt{\frac{2}{a}} \sin \frac{n\pi x}{L} e^{\frac{-iEt}{\hbar}}$$

Probability of finding the particle $P = \psi^* \psi$

$$P = \left(\sqrt{\frac{2}{a}} \sin \frac{n\pi}{a} \cdot \frac{a}{4} e^{\frac{+iEt}{\hbar}}\right) \cdot \left(\sqrt{\frac{2}{a}} \sin \frac{n\pi}{a} \cdot \frac{a}{4} e^{\frac{-iEt}{\hbar}}\right)$$

$$\boxed{P = \frac{2}{a} \sin^2 \frac{n\pi}{4}} \quad \text{------} \quad (11)$$

for $n = 1$,

$$P_1 = \frac{2}{a} \sin^2\left(\frac{\pi}{4}\right) = \frac{2}{a} \times \left(\frac{1}{\sqrt{2}}\right)^2 = \frac{1}{a}$$

For $n = 2$,

$$P_2 = \frac{2}{a} \sin^2\left(\frac{2\pi}{4}\right) = \frac{2}{a}$$

for $n = 3$,

$$P_3 = \frac{2}{a} \sin^2\left(\frac{3\pi}{4}\right) = \frac{2}{a} \sin^2 135 = \frac{2}{a} \times \left(\frac{1}{\sqrt{2}}\right)^2 = \frac{1}{a}$$

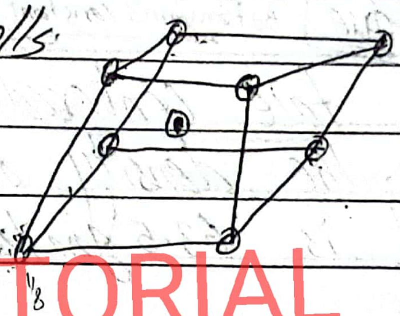
Hence, the probability of finding the particle in a well of width of position $x = \frac{a}{4}$ from the wall for $n = 1$, $n = 2$, $n = 3$ are $\frac{1}{a}$, $\frac{2}{a}$ and $\frac{1}{a}$ respectively.

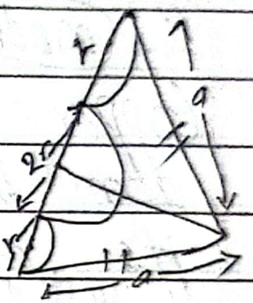
Assuming that atoms in a crystal structure are arranged in closed packed spheres. What is the ratio of the volume of the atoms to the volume available for the simple cubic structure. Assume one atom basis.

Q.N;11

=>

Total no. of 8 unit cells so that each corner atom contributes only $\frac{1}{8}$ of it's part. These are 8 corners. Hence, Total contribution is equal to $8 \times \frac{1}{8} = 1$





Representation of simple cubic structure of unit cell

Therefore, no. of atoms per unit cell = 1

From figure,

$$a = 2r$$

$$r = \frac{a}{2}$$

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Volume occupied by the atom in unit cell = $(v') = \frac{4}{3}\pi r^3$

$= \frac{4}{3}\pi\left(\frac{a}{2}\right)^3$

Volume of unit cell = $a^3 = V$

Ratio of volume of atom to the volume of unit cell

$= \frac{V'}{V}$

$= \frac{\frac{4}{3}\pi\left(\frac{a}{2}\right)^3}{a^3}$

$= 0.52$

The output of a digital circuit Y is given by this expression $Y = (CB + \bar{C}A)(\overline{BA})$ where A, B and C represent inputs. Draw a circuit of above equation using OR, AND and NOT gate and Hence, find its Truth Table.

Q.N;12

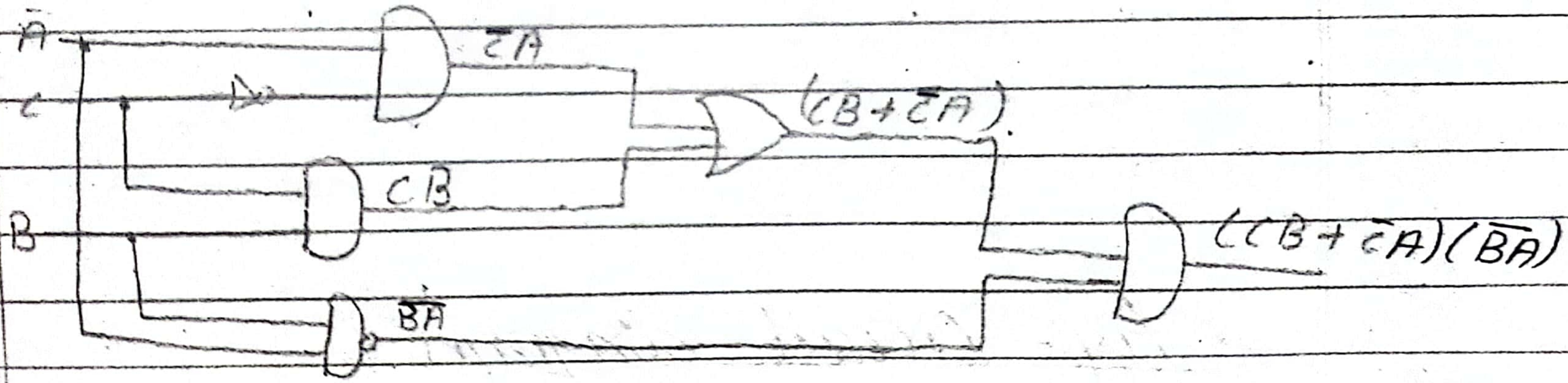

fig: circuit diagram

Truth Table

Input			Intermediate State						Output
A	B	C	CB	$\bar{C}$	$\bar{C}A$	BA	$\overline{BA}$	$(CB+\bar{C}A)$	Y
0	0	0	0	1	0	0	1	0	0
0	0	1	0	0	0	0	1	0	0
0	1	0	0	1	0	0	1	0	0
0	1	1	1	0	0	0	1	1	1
1	0	0	0	1	1	0	1	1	1
1	0	1	0	0	0	0	1	0	0
1	1	0	0	1	1	1	0	1	0
1	1	1	1	0	0	1	0	1	0