Q.2 a. What do you understand by atomic bonding? Explain the various types of bonds along with their characteristics.

Answer:

The arrangement of atoms in a material determines the behavior and properties of that material. The atomic or molecular interactions that occur within a substance determine its state. Matter is held together by forces originating between neighboring atoms or molecules which are known as atomic bonding. The types of bonds in a material are determined by the manner in which forces hold matter together.

Types of Bonds and Their Characteristics

Ionic bond - An atom with one or more electrons are wholly transferred from one element to another, and the elements are held together by the force of attraction due to the opposite polarity of the charge.

Covalent bond - Covalent bonding is formed by an equal sharing of electrons between two neighboring atoms each having incomplete outermost shells. The atoms do so in order to acquire a stable electronic configuration in accordance with the octet rule.

Metallic bond - The atoms do not share or exchange electrons to bond together. Instead, many electrons (roughly one for each atom) are more or less free to move throughout the metal, so that each electron can interact with many of the fixed atoms.

Molecular bond - When neutral atoms undergo shifting in centers of their charge, they can weakly attract other atoms with displaced charges. This is sometimes called the van der Waals bond.

Hydrogen bond - This bond is similar to the molecular bond and occurs due to the ease with which hydrogen atoms displace their charge.

b. Explain crystal directions and planes on the basis of Miller indices.

Answer: Refer Pages 31-33 of Text Book-I

Q.3 a. Define the term alloy. Describe three possible alloy microstructures and compare any two general characteristics with pure metals.

Answer:

An *alloy* is a mixture of two or more materials, at least one of which is a metal. Alloys can have a microstructure consisting of solid solutions, where secondary atoms are introduced as substitutionals or interstitials in a crystal lattice. An alloy might also be a crystal with a metallic compound at each lattice point. In addition, alloys may be composed of secondary crystals imbedded in a primary polycrystalline matrix. This type of alloy is called a composite.

Alloy microstructures
Solid solutions, where secondary atoms introduced as substitutionals or interstitials in a crystal lattice.

Crystal with metallic bonds.

Composites, where secondary crystals are imbedded in a primary polycrystalline matrix.

Two general characteristics as compared to pure metals:

Alloys are usually stronger than pure metals.

Although alloys generally have reduced electrical and thermal conductivities than pure metals.

b. Identify the three types of microscopic imperfections found in crystalline structures.

Answer:
Microscopic imperfections are generally classified as point, line, or interfacial imperfections.

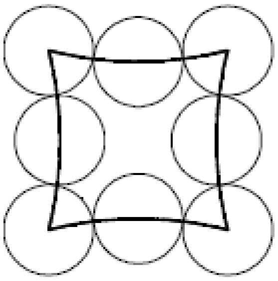
1. Point imperfections have atomic dimensions.

Point imperfections in crystals can be divided into three main defect categories.

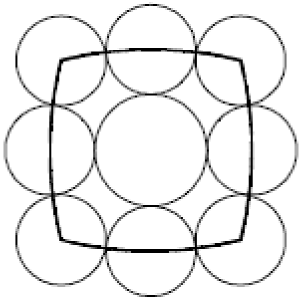
1. Vacancy defects result from a missing atom in a lattice position. The vacancy type of defect can result from imperfect packing during the crystallization process, or it may be due to increased thermal vibrations of the atoms brought about by elevated temperature.

2. Substitutional defects result from an impurity present at a lattice position.

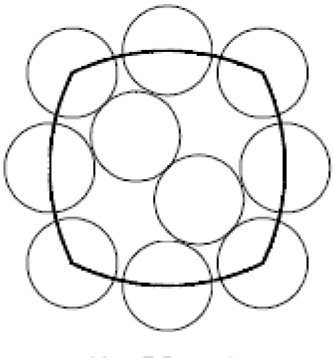
3. Interstitial defects result from an impurity located at an interstitial site or one of the lattice atoms being in an interstitial position instead of being at its lattice position. Interstitial refers to locations between atoms in a lattice structure.



VACANCY



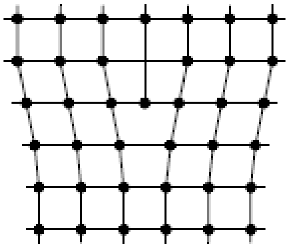
SUBSTITUTIONAL



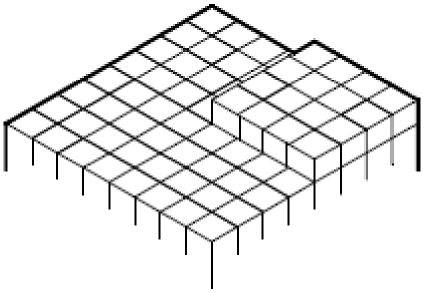
INTERSTITIAL

2. **Line imperfections or dislocations are generally many atoms in length.**

Line imperfections are called dislocations and occur in crystalline materials only. Dislocations can be an edge type, screw type, or mixed type, depending on how they distort the lattice. It is important to note that dislocations cannot end inside a crystal. They must end at a crystal edge or other dislocation, or they must close back on themselves. Edge dislocations consist of an extra row or plane of atoms in the crystal structure. The imperfection may extend in a straight line all the way through the crystal or it may follow an irregular path. It may also be short, extending only a small distance into the crystal causing a slip of one atomic distance along the glide plane (direction the edge imperfection is moving).



EDGE DISLOCATION



SCREW DISLOCATION

3. Interfacial imperfections are larger than line defects and occur over a two dimensional area.

Interfacial imperfections exist at an angle between any two faces of a crystal or crystal form. These imperfections are found at free surfaces, domain boundaries, grain boundaries, or interphase boundaries. Free surfaces are interfaces between gases and solids. Domain boundaries refer to interfaces where electronic structures are different on either side causing each side to act differently although the same atomic arrangement exists on both sides. Grain boundaries exist between crystals of similar lattice structure that possess different spacial orientations. Polycrystalline materials are made up of many grains which are separated by distances typically of several atomic diameters. Finally, interphase boundaries exist between the regions where materials exist in different phases (i.e., BCC next to FCC structures).

Q.4 a. The diffusion coefficient for Cr^{+3} in Cr_2O_3 is $6x10^{-15}$ cm^2/s at 727°C and is $1x10^{-9}$ cm^2/s at 1400°C. Calculate the activation energy and the diffusion constant D_0.

Answer:

(a) $$\frac{6\times 10^{-15}}{1\times 10^{-9}} = \frac{D_o \exp[-Q/(1.987)(1000)]}{D_o \exp[-Q/(1.987)(1673)]}$$

$$6\times 10^{-6} = \exp[-Q(0.000503 - 0.00030)] = \exp[-0.000203\,Q]$$

$$-12.024 = -0.000203\,Q \quad \text{or} \quad Q = 59{,}230 \text{ cal/mol}$$

(b) $$1\times 10^{-9} = D_o \exp[-59{,}230/(1.987)(1673)] = D_o \exp(-17.818)$$

$$1\times 10^{-9} = 1.828\times 10^{-8}\,D_o \quad \text{or} \quad D_o = 0.055 \text{ cm}^2/\text{s}$$

b. Discuss various factors affecting the resistivity of electrical materials.

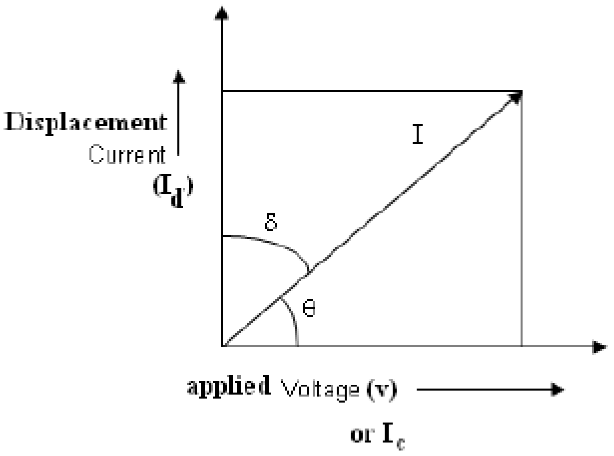
Answer: Refer Article 2.2, Pages 68-69 of Text Book-II

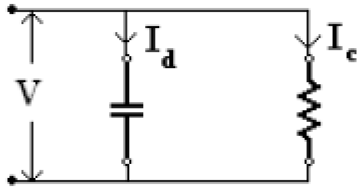
Q.5 a. Explain the terms dielectric constant and dielectric loss.

Answer:

Dielectric Constant or Permittivity: - Every insulating material possesses an electrical capacitance. The capacitance of such unit depends upon dimensions and kind of dielectric placed between the capacitor plates. The capacitance of a parallel plate capacitor may be calculated from the formula C =Î A/t where Î is the permittivity of the material in F/m, A =Area of the plates and t = thickness of dielectric. Also e = *C* / *C*0 , where C is the capacity in presence of dielectric and Co is the capacity in air or vacuum or in absence of dielectric. Thus permittivity Î of a material is a measurement of its ability to form an electrical capacitance of the insulating material, the dimensions of the capacitor being taken equal. Dielectric constant or permittivity is not a constant but varies with temperature and frequency.

Dielectric loss angle: - when an insulating material is subjected to alternating voltage, some of the electric energy is absorbed by the insulation and is dissipated as heat. Energy absorbed by the material in unit time is called dielectric loss. A perfect dielectric has a current, which leads the voltage by 900, but the practical dielectric material has a current, which leads the voltage by less than 900. The dielectric phase angle is q and d = 900 - q is the dielectric loss angle.





Also I is the phasor sum of Id and Ic , where Ic is the conduction current which is in phase with the applied voltage and Id is the displacement current which is in quadrature phase with applied voltage.

b. **Explain the various types of polarization phenomena in a dielectric material and the effect of applied electric field frequency on them.**

Answer:

Polarization : When a material is placed in an electric field, e.g. between the plates of a condenser, the field strength of charged particles within the material interact with the electric field. If the material is non-conducting or insulator (dielectric), electrons can only be displaced locally as they are bound to the individual atoms. This local displacement of electrons, however, is sufficient to polarize the material. The negative electron cloud is displaced in each atom relative to the positive nucleus, thereby creating a small induced dipole whose negative pole is toward the positive side of the electric field. All dielectric materials are subjected to such *electronic polarization.*

Polarization is of three types.

Electric polarization: The electric polarization **P** is defined as the difference between the electric fields **D** (induced) and **E** (imposed) in a dielectric due to bound and free charges, respectively.

Ionic polarization is polarization which is caused by relative displacements between positive and negative ions in ionic crystals (for example, NaCl). If crystals or molecules do not consist of only atoms of the same kind, the distribution of charges around an atom in the crystals or molecules leans to positive or negative. As a result, when lattice vibrations or molecular vibrations induce relative displacements of the atoms, the centers of positive and negative charges might be in different locations. These center positions are affected by the symmetry of the displacements. When the centers don't correspond, polarizations arise in molecules or crystals. This polarization is called **ionic polarization**.
Ionic polarization causes ferroelectric transition as well as dipolar polarization. The transition which is caused by the order of the directional orientations of permanent dipoles along a particular direction is called **order-disorder phase transition**. The transition which is caused by ionic polarizations in crystals is called **displacive phase transition.**

Dipolar polarization is a polarization that is particular to polar molecules. This polarization results from permanent dipoles, which retain polarization in the absence of an external electric field. The assembly of these dipoles forms a macroscopic polarization.

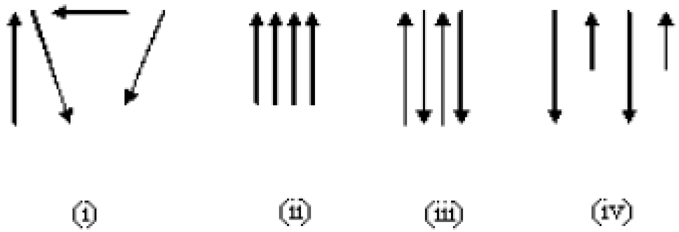
Effect of frequency of applied electric field:
When an external electric field is applied, the distance between charges, which is related to chemical bonding, remains constant in the polarization; however, the polarization itself rotates. Because this rotation completes not instantaneously but in the delay time, which depends on the torque and the surrounding local viscosity of the molecules, dipolar polarizations lose the response to electric fields at the lowest frequency in polarizations. The delay of the response to the change of the electric field causes friction and heat.

Q.6 a. Distinguish between the characteristics of dia, para and ferro magnetism. Give an example of each type of material. Comment on the temperature variation of susceptibility of all types of materials.

Answer:

Magnetic materials for which linear relationship between M and H exists are divided into classes depending upon the sign of χ (magnetic susceptibility). Materials, which have negative value of χ the order of 10^{-4} to 10^{-6} are called diamagnetic and those which have a positive value of χ of about the same order of magnitude are called paramagnetic. When the relationship between M and H is non-linear and exhibits hysteresis effect, this group of materials in which the resultant magnetization is one to several orders of magnitude. Such materials are called Ferromagnetic materials.

Another classification of magnetic materials consists in the presence or absence of permanent magnetic dipolar in them, Materials, which lack permanent magnetic dipoles, are called diamagnetic. If permanent magnetic dipoles are present in the atoms of a material, it may be paramagnetic, ferromagnetic, anti- ferromagnetic of ferrimagnetic depending on the interaction between the individual dipoles. Thus, if the interact between the atomic permanent dipoles moments is zero or negligible and the individual dipole moments are oriented at random as shown in fig.



The material will be paramagnetic. If the dipole interact in such a manner that they tend to line up in parallel, as shown in fig (ii), the material will be ferromagnetic. When neighboring moments are aligned anti parallel as shown in fig (iii), the materials are anti- ferromagnetic.
In ferromagnetic materials, there is a large resultant magnetization, whereas in antiferromagnetic materials the magnetisation vanishes. When the order of the magnetic moments is as shown in fig (iv), the phenomena is known as ferrimagnetisms.

Examples of diamagnetic materials are Diamonds, Graphite and copper etc.
Examples of paramagnetic materials are Aluminium , Ebonite & platinum etc.
Examples of Ferromagnetic materials are Iron, cobalt and Nickel etc.

b. Write the properties and application of permanent magnetic materials.

Answer:

Properties of Permanent magnetic materials:
i. These materials have a large area of hysterisis loop.
ii. They have large retentivity and coercivity.
iii. High saturation values.
iv. High residual magnetism
v. These materials are hard to be magnetized.

Applications: These materials are used to make permanent which finds application in relays, electric machines, measuring instruments, microwave devices, loudspeakers.

Q.7 a. Why at a very high temperature, the p type and n type semiconductor behaves like intrinsic semiconductor?

Answer:

When the temperature of *N*-type semiconductor is raised, the number of electron-hole pairs due to thermal excitations from the valence band to the conduction band will increase. The number of electrons coming from the donor level will remain constant as the donor atoms are already ionized. Obviously, at very high temperature the concentration of thermally generated free electrons from the valence band will be much larger than the concentration of free electrons contributed by the donors. At this situation the hole and the electron concentrations will be nearly equal and the semiconductor will behave like an intrinsic one. On the basis of the same argument, one can say that a *P*-type semiconductor will also behave as intrinsic semiconductor at very high temperature. Generalizing, we can say that as the temperature of an extrinsic semiconductor increases the semiconductor passes from an extrinsic to an intrinsic one.

b. Explain the effect of doping on electrical conductivity of semiconductor. Compute the conductivity of Ge at 300K if the intrinsic carrier concentration for Ge is 7.2 x 10^{19}/m^3(given that electron mobility (μ_e) =0.38 and hole mobility (μ_p) =0.18).

Answer:

The electrical conductivity of a semiconductor increases significantly on doping.

The intrinsic carrier concentration (*ni*) for Ge is 7.2 x 10^{19}/m^3. The conductivity of Ge in terms of electron mobility (μ_e) and hole mobility (μ_p) is

$$\sigma = n_i e(\mu_e + \mu_p)$$
$$= 7.2x10^{19}\,x1.6x10^{-19}(0.38 + 0.18)$$
$$= 6.68\Omega^{-1}m^{-1}$$

c. A magnetic field of 0.8 tesla is imposed on a 20 mm thick aluminum specimen in a direction perpendicular to a current of 30 A flowing through it. If the electrical conductivity and electron mobility for aluminum are 3.8 ×10^7(Ω-m)$^{-1}$ and 0.0012 m^2/V-s, respectively, Calculate the Hall voltage.

Answer:

Hall coefficient and hall voltage is calculated as follows.

$$R_{\mathrm{H}} = -\frac{\mu_e}{\sigma}$$
$$= -\frac{0.0012\ \mathrm{m^2/V\text{-}s}}{3.8 \times 10^7\ (\Omega\text{-m})^{-1}} = -3.16 \times 10^{-11}\ \mathrm{V\text{-}m/A\text{-}tesla}$$

$$V_H = \frac{R_H I_x B_z}{d} = \frac{(-3.16x10^{-11})(30)(0.8)}{20x10^{-3}} = 3.792x10^{-8}V$$

Q.8 Discuss in detail any two among the following
(i) Zener diode and avalanche diode
(ii) Mica and Mica Products
(iii) Ceramics

Answer:

(i) Zener diode and avalanche diode

Zener diode' and 'avalanche diode' are terms often used interchangeably, with the former much more common. Both refer to breakdown of a diode under reverse bias. Specifically, when a diode is reverse biased, very little current flows, and the diode is to a first order approximation an open circuit. As the reverse voltage is increased, though, a point is reached where there is a dramatic increase in current. Equivalently, there is a dramatic reduction in the dynamic resistance (slope of the V-I curve) that can be as low as 1- 2 W in this region. This voltage is called the reverse breakdown voltage and it is fairly independent of the reverse current flowing. This property makes it ideal as a voltage reference.

Avalanche breakdown occurs in lightly-doped pn-junctions where the depletion region is comparatively long. The doping density controls the breakdown voltage. The temperature coefficient of the avalanche mechanism is positive. That is, as the temperature increases, so does the reverse breakdown voltage. The magnitude of the temperature coefficient also increases with increasing breakdown voltage. For example, the temperature coefficient of a 8.2 V diode is in the range 3 - 6 mV/K while the temperature coefficient of an 18 V diode is in the range of 12 - 18 mV/K.

Zener breakdown occurs in heavily doped pn-junctions. The heavy doping makes the depletion layer extremely thin. So thin, in fact, carriers canít accelerate enough to cause impact ionization. With the depletion layer so thin, however, quantum mechanical tunneling through the layer occurs causing current to flow. The temperature coefficient of the Zener mechanism is negative the breakdown voltage for a particular diode decreases with increasing temperature. However, the temperature coefficient is essentially independent of the rated breakdown voltage, and on the order of -3 mV/K.

In a 'Zener' diode either or both breakdown mechanisms may be present. At low doping levels and higher voltages the avalanche mechanism dominates while at heavy doping levels and lower voltages the Zener mechanism dominates. At a certain doping level and around 6 V for Si, both mechanism are present with temperature coefficients that just cancel. It is possible to make Zener diodes with quite small temperature coefficients.

Neither Zener nor avalanche breakdown are inherently destructive in that the crystal lattice is damaged. However, the heat generated by the large current flowing can cause damage, so either the current must be limited and/or adequate heat sinking must be supplied.

(ii) **Mica and Mica Products –** Mica is an inorganic material. It is one of the best insulating materials available. From the electrical point of view, mica is of two types –

Muscovite mica – Chemical composition is KH2Al3(SiO4)3. The properties are

i) Strong, tough and less flexible
ii) Colourless, yellow, silver or green in colour
iii) Insulating properties are very good
iv) Abrasion resistance is high
v) Alkalies do not affect it

Uses – Muscovite mica is used where electrical requirements are severe. Because of high dielectric strength, it is used in capacitors. It is also used in commutators due to high abrasion resistance.

Phologopite mica – Chemical composition is KH(MgF)8MgAl(SiO4)3. The properties are

i) Amber, yellow, green or grey in colour
ii) Greater structural stability, being tougher and harder than muscovite mica, less rigid
iii) Resistant to alkalies, but less to acids
iv) Greater thermal stability than that of muscovite mica

Uses – It is used when there is greater need of thermal stability as in domestic appliances like irons, hotplates, toasters.

Applications – It is used for the manufacturing of protective clothing such gloves, boots. It is used as an insulation covering for wires and cables.

Mica products

(i) Glass bonded mica – Ground mica flakes and powdered glass when moulded makes glass bonded mica. This material is impervious to water and chemically stable. This is used in high humidity and high ambient temperatures.
(ii) Mica paper and Mica sheet– Mica is broken into small particles in aqueous solution.

Out of this sheets of mica paper are produced which are used as insulation for armature and field coils of rotating machines. Also used as washers, spacers, sleeves, tubes etc.

(iii) Manufactured mica – Mica flakes held together with adhesives is called manufactured mica. It is used in commutators, electrical heating devices, motor slot insulation, transformers, etc.

(iii) **Ceramics –** Ceramics are materials made by high temperature firing treatment of natural clay and certain inorganic matters. The properties of ceramics are –

i) Ceramics are hard, strong and dense.
ii) Ceramics are not affected by chemical action except by strong acids and alkalies.
iii) Stronger in compression than in tension.
iv) Excellent dielectric properties.
v) Stable at high temperatures.

Uses – The capacity to withstand high temperature, immunity to moisture, good electrical properties make ceramics valuable for the use in different types of insulators, transformer bushing pins, fuse holders, plugs and sockets.

Main ceramic materials are

(a) Porcelain – It is used in low frequency applications due to high dielectric loss factor. It has low electrical resistivity.

(b) Steatite – These are low dielectric loss porcelains, used for variable capacitor coils, switches, resistor shafts and bushings. It is also used for low voltage and high frequency applications.

(c) Alumina – It has high mechanical and dielectric strength. It also has high electrical resistivity and low dielectric losses. It is chemically stable and retains its properties over a wide range of temperature and frequencies. It is used for circuit breakers, spark plugs, resistor cores, integrated circuits and power transistors.

(d) Zirconia – It has poor thermal conductivity and shock resistance. It is available with calcium or yttrium. It is used for high temperature heating elements.

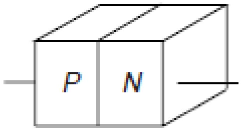
Q.9 a. Explain grown junction and alloyed junction process during the formation of a p-n junction.

Answer:

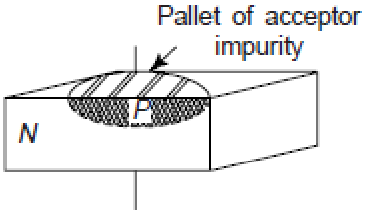
Formation of a P-N Junction: Figure shows three types of such junctions.

P and *N* regions have been grown into the germanium block by mixing acceptor and donor impurities, respectively, into the single crystal during its formation. This is known as a **grown junction**. It is worthwhile to mention that the grown type of *P*-*N* junction is not a sandwich made by attaching a *P* block to a *N* block, but actually consists of *P* and *N* layers in a single piece of germanium.

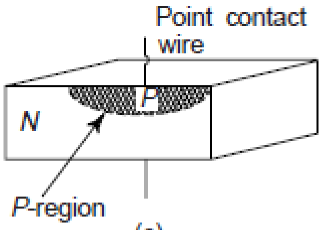
The **diffused junction** is made by placing a pellet of acceptor impurity, such as indium, on one face of a wafer of *N*-type germanium and then heating the combination to melt the impurity. Under proper conditions of temperature and time, a portion of the impurity metal will diffuse a short distance into the wafer, thereby creating a region of *P*-type germanium in intimate association with W-type bulk. This is also called an ***alloyed junction*** or fusion-alloy junction from the fact that a small amount of pellet material alloys with the germanium.



(a)
Grown *P-N*
junction



(b)
Diffused *P-N*
junction

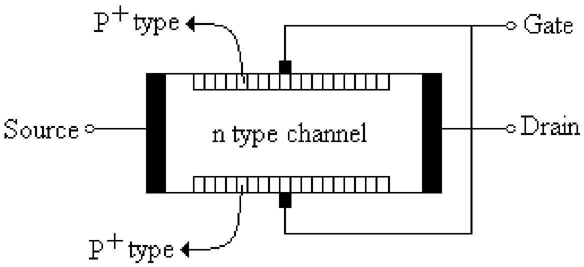


(c)
Point contact *P-N*
junction

b. **Describe the construction and operation of JFET. Draw the equivalent circuit of a JFET. (8)**

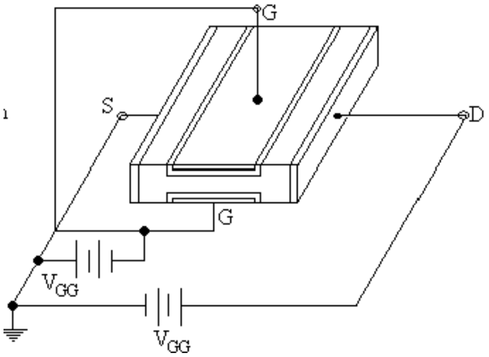
Answer:

The basic structure of an n-channel JFET is as shown in Fig. The drain and source terminals are made by ohmic contacts at the ends of n-type semiconductor bar. Gate is formed by electrically connecting two shallow p+ regions. The n-type region between two p+ gates is called the channel through which majority carriers flow between the source and the drain.



Operation:

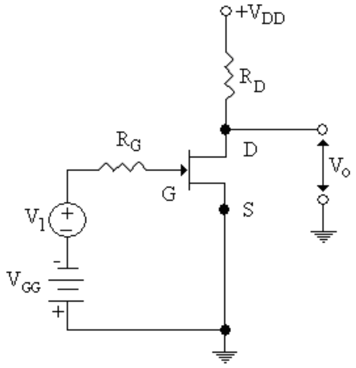
Gate regions and channel constitute pn junction. In normal operating mode, this pn junction is maintained in reverse biased state. Gate to source voltage is negative and drain to source voltage is positive. This reverse biases the junction, and hence the depletion region exists. The depletion region contains immobile charges.



Also, depletion region extends more into region of lower doping. Since gate region is heavily doped than the channel region, depletion region penetrates more deeply into the channel. The conductivity of this region is nominally zero because of unavailability of charge carriers.

Therefore, as reverse bias increases, the effective width of the channel decreases. At specific value of gate to source voltage (VGS) the channel width becomes zero because all the free charges have been removed from the channel. This voltage is called pinch off voltage (Vp).

Therefore, for a fixed drain to source voltage, the drain current will be a function of reverse bias voltage across the gate junction. The signal to be amplified is V1. VGG provides the necessary reverse bias between gate and source of JFET. This is the biasing arrangement for the peration of JFET as an amplifier.



TEXT BOOK

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