Semiconductor Materials and properties.

Semiconductor Materials Ge, Si and GaAs:

- Semiconductors are a special class of elements having a conductivity between that of a good conductor and that of an insulator.
- Semiconductor materials fall into two classes
  1- Single Crystal
  2- Compound crystal.
- The three semiconductors used most frequently in the construction of electronic devices are Ge, Si and GaAs.
- In semiconductor material conductivity roughly in the range of 10^3 and 10^{-8} siemens per centimeter.
- Common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are also known.

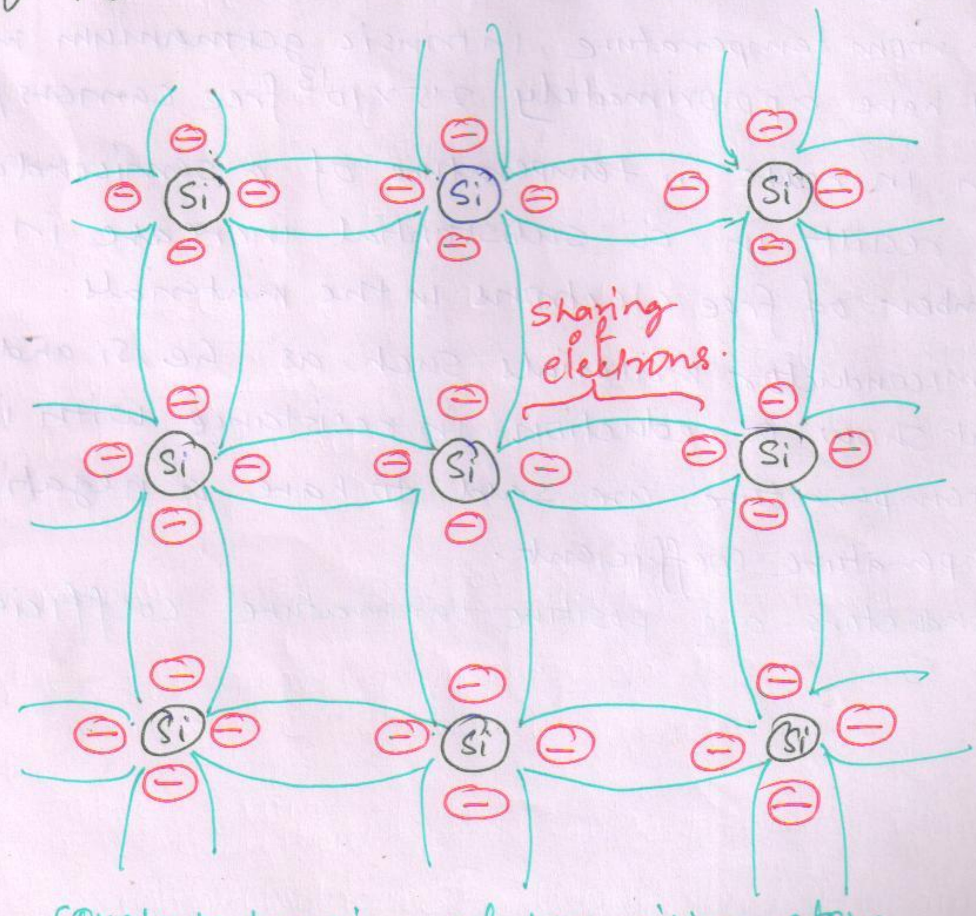
Group IV materials:

- Semiconductor materials are nominally small band gap insulators.
- Most commonly used semiconductor materials are crystalline inorganic solids.
- These materials are classified according to the periodic table group of their constituent atoms.
- Different semiconductor materials differ in their properties.

- when Diode (in 1939) and transistor (in 1947) were found, germanium (Ge) was used almost exclusively because it was relatively easy to find and was available in fairly large quantities.
- It was relatively easy to refine to obtain very high levels of purity, an important aspect in the fabrication process.
- Devices constructed using germanium as the base material suffered from low levels of reliability due primarily to its sensitivity to change in temperature.
- Finally, in 1954 first silicon transistor was introduced.
- Silicon quickly became the semiconductor material of choice.
- It is one of most abundant materials on earth.
- It is also less temperature sensitive.
- At time moved, the field of electronics became increasingly sensitive to issues of speed. A semiconductor material capable of meeting these new needs had to be found.
- first GaAs transistor comes in 1970s. This new transistor had speeds of operation up to five times that of Si.
- GaAs was more difficult to manufacture at high levels of purity, was more expensive, and had little design support earlier.

Covalent Bond

- A covalent bond is a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms when they share electrons is known as covalent bonding.
- Covalent bonding includes many kinds of interaction, including σ-bonding, π-bonding, metal to metal bodding, agostic interactions, and three-center two electron bonds.
- A pure semiconductor crystal (Group IV materials) the four valence electrons of one form a bonding arrangement with four adjoining atoms as shown in following figure:



Covalent bonding of the silicon atom

- Although the covalent bond will result in a stronger bond between the valence electrons and their parent atom, it is possible for the valence electron to absorb sufficient kinetic energy from natural causes to break the covalent bond and assume the free state.
- At room temperature there are approximately 1.5×10^{10} free carriers in a cubic centimeter of intrinsic silicon material.

Intrinsic Materials.

- Intrinsic materials are those semiconductors that have been carefully refined to reduce the impurities to a very low level — essentially as pure as can be made available through modern technology.
- At room temperature, intrinsic germanium material will have approximately 2.5×10^{13} free carriers/cm^3.
- An increase in temperature of a semiconductor can result in a substantial increase in the number of free electrons in the materials.
- Semiconductor materials such as Ge, Si and GaAs that show a reduction in resistance with increase in temperature are said to have a negative temperature coefficient.
- Conductors are positive temperature coefficient.

Extrinsic Materials. n- and p-type.

- At room temperature intrinsic semiconductor has very poor conductivity.
- At absolute (273 k) or (0°c) temperature intrinsic Semiconductor behaves as insulator.
- By addition of certain impurity (perhaps 1 part in 10 million) can alter the band structure sufficiently to totally change the electrical properties of material.
- A semiconductor material that has been subjected to the doping process is called an extrinsic material.
- There are two extrinsic materials of immeasurable importance to semiconductor device fabrication

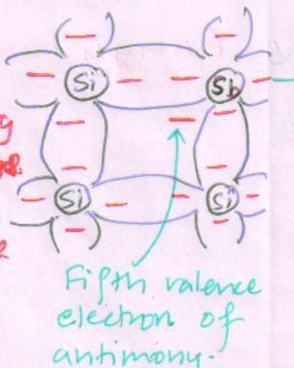
1- n-type } Both the n- and p-type materials are
2- p-type } formed by adding a predetermined number of impurity.

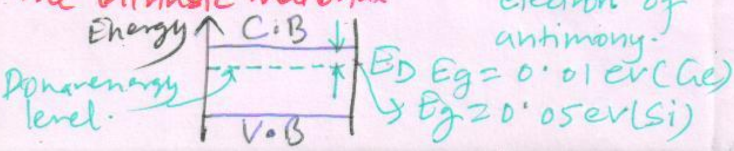
n-type Material

→ n-type is created by introducing those impurity elements have five valence electrons (pentavalent), such as Sb, As, P

→ Diffused impurities with five valence electrons are called donor atoms.

→ As shown in energy band a discrete energy level (donor level) appears in the forbidden band with Eg significant less than of the intrinsic material



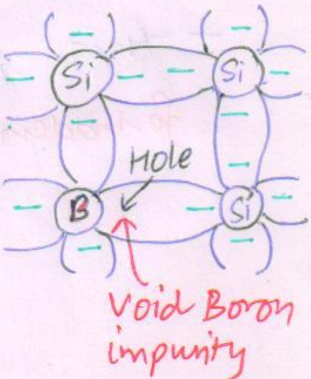


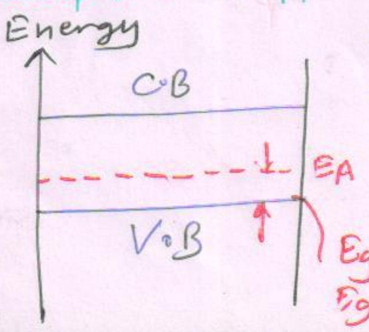
p-type Material

→ p-type is created by introducing those impurity elements have three valence electrons (trivalent), such as B, Ga, Ir.

→ Diffused impurities with three valence electrons are called acceptor atoms.

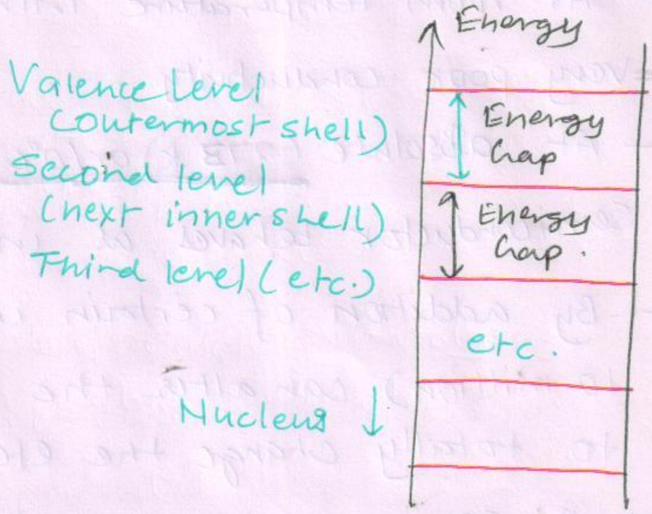
→ Similarly in p-type acceptor level appears.

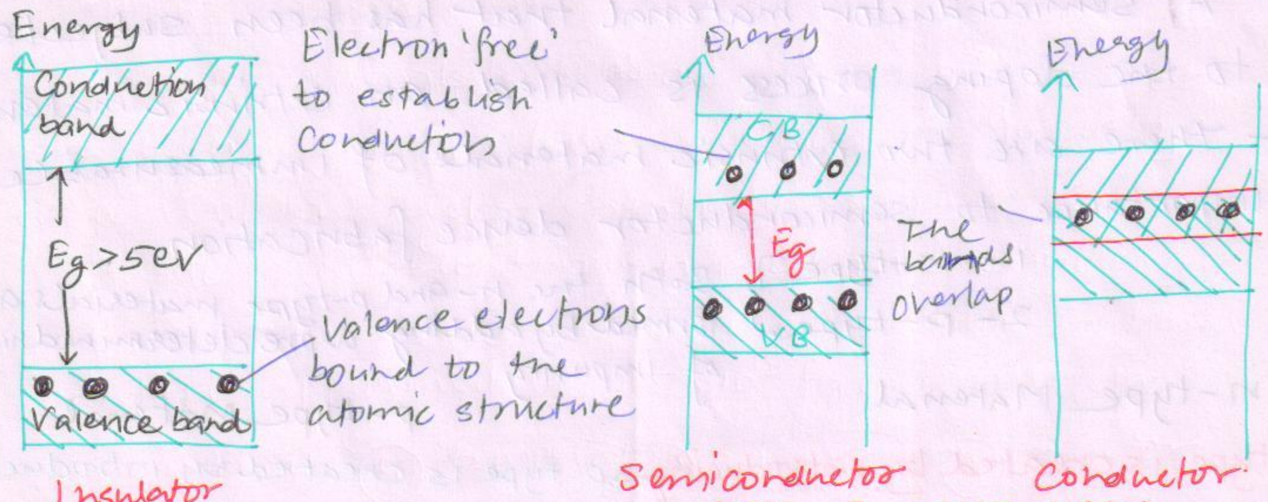




Energy levels and Energy Band, Energy Gap

- The more distant the electron from the nucleus, the higher the energy state, and any electron that has left its parent atom has higher energy state than any electron in the atomic structure.





$E_g = 1.1\,eV\,(Si)$ $E_g = 0.67\,eV\,(Ge)$

$E_g = 1.41\,eV\,(GaAs)$

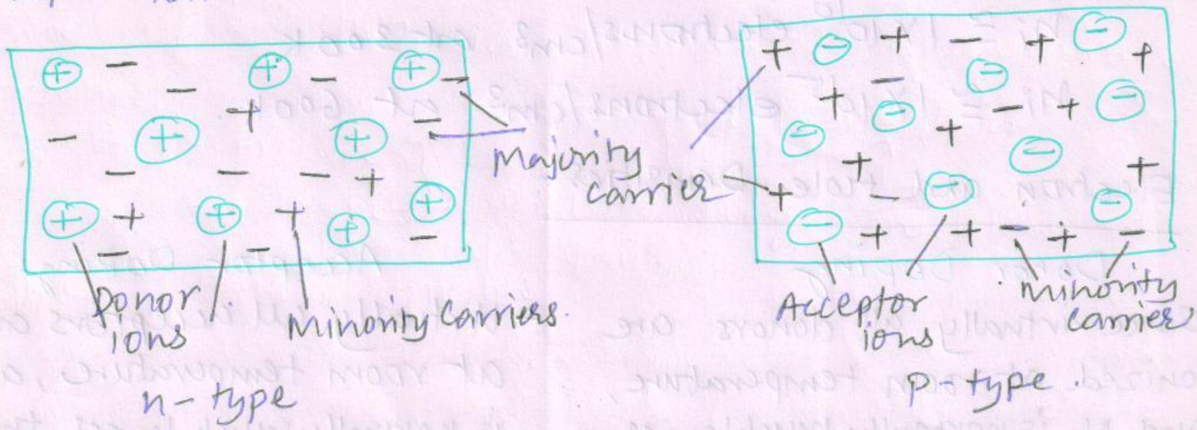
- There remains a forbidden region between the valence band and the ionization level (conduction band)
- This gap is known as Energy band gap or forbidden Gap.

Majority and Minority Carriers

- In an n-type material the electron is called the majority carrier and hole the minority carrier.
- In a p-type material hole is the majority carrier and the electron is the minority carrier.

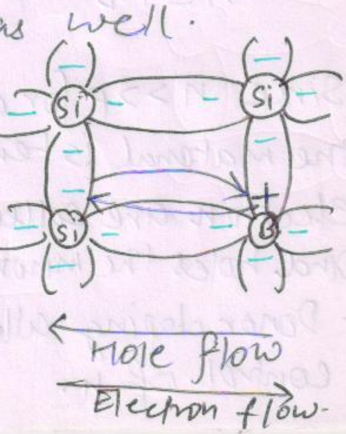
Donor Impurities and Acceptor Impurities

- When the fifth electron of a donor atom leaves the parent atom, the atom remaining acquires a net positive charge hence positive sign appears in the accepto
- Similarly the negative sign appears in the acceptor ion.



Electron - Hole Pair Generation

- When a conduction electron is thermally generated a "hole" is also generated.
- A hole is associated with a positive charge, and is free to move about the Si lattice as well.
- If a valence electron acquires sufficient kinetic energy to break its covalent bond and fills the void created by a hole, then a vacancy, or hole, will be created in the covalent bond that released the electron.



Carrier Concentration

Mass-Action Law

- For intrinsic material $n = p = n_i$ therefore

$$np = n_i^2$$

- This turns out to be a general relationship called the mass-action law, which can be used for doped material in equilibrium.
- The band gap energy E_g is the amount of energy.
- The concentration of conduction electrons in intrinsic silicon n_i, depends exponentially on E_g and absolute temperature (T)

$$n_i = 5.2 \times 10^{15} T^{3/2} \exp \frac{-E_g}{2kT} \text{ electrons/cm}^3$$

$$n_i \cong 1 \times 10^{10} \text{ electrons/cm}^3 \text{ at } 300K$$

$$n_i \cong 1 \times 10^{15} \text{ electrons/cm}^3 \text{ at } 600K.$$

Electron and Hole Densities.

Donor Doping

- Since virtually all donors are ionized at room temperature, and N_D is normally much larger than n_i, the electron density n is essentially just the density of donors, with p given by mass action law

$$n \simeq N_D \quad p \simeq \frac{n_i^2}{n} = \frac{n_i^2}{N_D}$$

- Since $n >> p$ for donor doping, the material is termed n-type, electron are called the majority and holes the minority carriers.
- Donor doping allows direct control of n.

Acceptor Doping

- Virtually all acceptors are ionized at room temperature, and N_A is normally much larger than n_i, the valence band hole density p is essentially just the density of acceptors, with n given by the mass action law

$$p \simeq N_A \quad n \simeq \frac{n_i^2}{p} = \frac{n_i^2}{N_A}$$

- Since $p >> n$ for acceptor doping the material is termed p-type. Holes are called the majority and electrons the minority carrier.
- Acceptor doping allows direct control of p