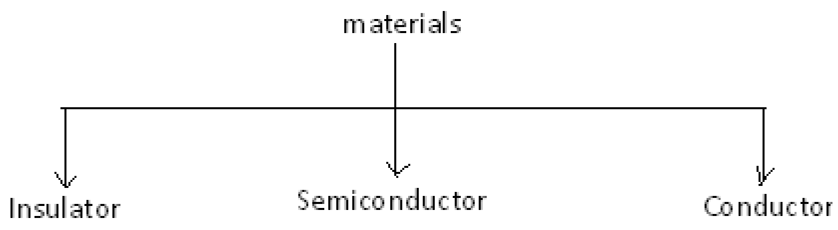
ELECTRONIC DEVICES AND CIRCUITS SUMMARY

Classification of Materials:

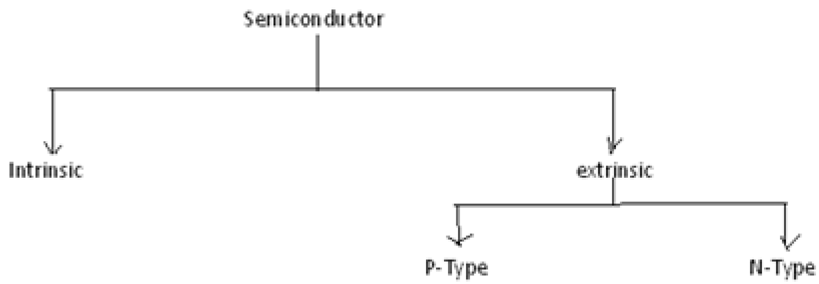


Insulator: An insulator is a material that offers a very low level (or negligible) of conductivity when voltage is applied. Eg: Paper, Mica, glass, quartz. Typical resistivity level of an insulator is of the order of 1010 to 1012 Ω-cm.

Conductors: A conductor is a material which supports a generous flow of charge when a voltage is applied across its terminals. i.e. it has very high conductivity. Eg: Copper, Aluminum, Silver, Gold. The resistivity of a conductor is in the order of 10-4 and 10-6 Ω-cm.

Semiconductor: A semiconductor is a material that has its conductivity somewhere between the insulator and conductor. The resistivity level is in the range of 10 and 104 Ω-cm.

Semiconductor Types:



A pure form of semiconductors is called as intrinsic semiconductor. Conduction in intrinsic sc is either due to thermal excitation or crystal defects. Si and Ge are the two most important semiconductors used.

EXTRINSIC SEMICONDUCTOR:

Intrinsic semiconductor has very limited applications as they conduct very small amounts of current at room temperature. The current conduction capability of intrinsic semiconductor can be increased significantly by adding a small amounts impurity to the intrinsic semiconductor. By adding impurities it becomes impure or extrinsic semiconductor. This process of adding impurities is called as doping. The amount of impurity added is 1 part in 106 atoms.

N type semiconductor: If the added impurity is a pentavalent atom then the resultant semiconductor is called N-type semiconductor. Examples of pentavalent impurities are Phosphorus, Arsenic, Bismuth, Antimony etc.

P type semiconductor: If the added impurity is a trivalent atom then the resultant semiconductor is called P-type semiconductor. Examples of trivalent impurities are Boron, Gallium , indium etc.

SEMICONDUCTOR PHYSICS

Electron - an elementary negatively-charged particle. (cf. photon)

Hole - the absence of an electron in a crystal bond which is mathematically equivalent to a mobile positively-charged particle.

Elemental Semiconductor - a semiconductor composed of a single species of atom. They are found in column IV (periodic table) and include silicon (Si) and germanium (Ge).

Compound Semiconductor - a semiconductor composed of two or more species of atom. They are formed from some combinations of elements in columns II, III, IV, V, and VI.

Common Binary III-V Semiconductors: GaAs, AlP, InSb, and InP

Common Binary II-VI Semiconductors: ZnSe, CdTe, and CdSe

Common Ternary Semiconductor: GaAsP and AlGaAs

Common Quaternary Semiconductors: GaInAsP and AlGaAsSb

Intrinsic Semiconductor - a semiconductor containing no impurity atoms or an insignificant amount of impurity atoms such that its properties are native to the material.

Extrinsic Semiconductor - a semiconductor in which impurities control electrical properties.

Dopants - specific impurity atoms which are incorporated in controlled amounts for the express purpose of increasing the concentrations of electrons or holes.

Donors - impurity atoms which increase the concentration of mobile electrons.

Acceptors - impurity atoms which increase the concentration of holes.

Majority Carrier - the most abundant charge carrier in a semiconductor.

Minority Carrier - the least abundant charge carrier in a semiconductor.

n-type Material - a semiconductor having electrons as the majority carriers.

p-type Material - a semiconductor having holes as the majority carriers.

SEMICONDUCTOR DEVICES

Electronics - science and technology concerned with the behavior of electrons.

Homo- (junction or structure) – an interface, e.g. pn, in the same semiconductor.

Hetero- (junction or structure) – an interface between different bandgap semiconductors.

Step-junction – an interface between n-type and p-type material with an abrupt doping change.

Diode - the two-terminal device with p-type and n-type regions in which the electrical behaviour differs for forward and reverse bias.

Transistor – a three-terminal device for which the voltage or current at one terminal controls the electrical behavior of the other terminals.

Field Effect Transistor or FET - a three-terminal device for which the voltage at one terminal controls the electrical behavior of the other terminals.

Bipolar Junction Transistor or BJT - a three-terminal device for which the current at one terminal controls the electrical behavior of the other terminals.

Operational Amplifier or Op Amp – a complex device that may be modeled as a voltagecontrolled voltage source with high gain, high input impedance, and low output impedance.

Equilibrium - carrier concentrations are unchanging and are determined only by host material, impurities, and temperature.

Steady-state - carrier concentrations are unchanging without transients from external conditions.

Ohmic Contact - a perfect source or sink of both holes and electrons with no tendency to inject or collect either carrier type.

PHOTONIC RELATIONSHIPS

Electromagnetic (EM) Spectrum - radiation of all frequencies or wavelengths including

electrical power transmission, radio frequencies, optical frequencies, and high-energy rays.

Wavelength λ (in vacuum) or frequency f are related by $\lambda f = c$ = speed of light in vacuum.

Radiation - energy emitted or propagated as waves and energy quanta.

Photon - a quantum of electromagnetic energy with no mass, no charge, and energy hc/λ.

Light - electromagnetic radiation in the ultraviolet, visible, and infrared bands or optical range.

Infrared Spectrum (IR) - EM band with wavelengths between about 700 nm and 105 nm.

Visible Spectrum - EM band with wavelengths between about 450 nm and 700 nm; radiation

detectable by the human eye.

Ultraviolet Spectrum (UV) - EM band with wavelengths between about 1 nm and 450 nm.

X-rays - electromagnetic radiation with wavelengths between about 10 nm and 0.01 nm; usually described as high-energy photons.

Photonics - science and technology concerned with the behavior of photons.

Optoelectronics - the technology in which optical radiation is emitted, modified, or converted (as in electrical-to-optical or optical-to-electrical).

Photodiode (PD) – an optoelectronic device that is based on a semiconductor junction which absorbs light and converts the light input to a current.

Laser – (light amplification by stimulated emission radiation) a device that emits optical radiation which is coherent, highly directional, and nearly monochromatic.

Laser Diode (LD) – an optoelectronic device that is based on a semiconductor junction which emits optical laser radiation at a photon energy close to bandgap of the junction.

Light Emitting Diode (LED) – an optoelectronic device which emits non-coherent optical radiation at a photon energy close to bandgap of the junction.

Radiometry – the measurement of radiant EM energy at specific wavelength ranges.

CONSTANTS AND MATERIALS

IMPORTANT CONSTANTS AND UNITS

Electron Charge q = 1.602 x 10-19 C

Electron Mass m = 9.109 x 10-31 kg

Permeability (Vacuum) μo = 4π x 10-9 H/cm

Permittivity (Vacuum) εo = 8.854 x 10-14 F/cm

Speed of Light (Vacuum) c = 2.998 x 1010 cm/s

Planck's Constant h = 4.136 x 10-15 eV-sec = 6.626 x 10-34 J-sec

Boltzmann's Constant k = 1.38 x 10-23 J/K = 8.62 x 10-5 eV/K

Electron-Volt 1 eV = 1.602 x 10-19 J

Avogadro's Number NA = 6.02 x 1023 molecules per mole

RT* Value of kT kT = 0.0259 eV

*RT = Room Temperature (300 K)

PROPERTIES OF SELECTED SEMICONDUCTORS

Diamond Carbon (C) Bandgap at RT: EG = 5.5 eV

Lattice Constant: a = 0.3567 nm

Silicon (Si) Bandgap at RT: EG = 1.12 eV

Lattice Constant: a = 0.5431 nm

Intrinsic Mobility for Electrons: μN = 1450 cm2 /V s

Intrinsic Mobility for Holes: μP = 500 cm2 /V s

Germanium (Ge) Bandgap at RT: EG = 0.67 eV

Lattice Constant: a = 0.5658 nm

Intrinsic Mobility for Electrons: μN = 3900 cm2 /V s

Intrinsic Mobility for Holes: μP = 1800 cm2 /V s

Gallium Arsenic (GaAs) Bandgap at RT: EG = 1.42 eV

Lattice Constant: a = 0.5653 nm

Intrinsic Mobility for Electrons: μN = 9200 cm2 /V s

Intrinsic Mobility for Holes: μP = 400 cm2 /V s

COMMON VALUES FOR INTRINSIC CARRIER CONCENTRATIONS

Silicon (Si) Intrinsic concentration at RT: nI = 1.5 x 1010 cm-3

Germanium (Ge) Intrinsic concentration at RT: nI = 2.3 x 1013 cm-3

Gallium Arsenic (GaAs) Intrinsic concentration at RT: nI = 2.1 x 106 cm