BME 202 Electronics

Lecture 1: Semiconductor Diodes

Semiconductor Materials

- Conductors – electrical charge carriers move easily when a voltage is applied
- Insulators – a material of very low conductivity, in which electrical charge carriers can not easily move
- Semiconductors – a special class of elements having a conductivity between that of a conductor and insulator.

most frequently use semiconductors in electronic circuits: *Ge*, *Si*, and *GaAs*

Atomic Structure

- electron, proton, and neutron
- atomic structure and crystalline formation
- Bohr model
- valence electrons

	# of electrons	# of valence electrons	
Silicon	14	4	tetravalent
Germanium	32	4	tetravalent
Gallium	31	3	trivalent
Arsenic	33	5	pentavalent

Covalent Bonding and Intrinsic Materials

- *covalent bonding*: bonding of atoms sharing valence electrons
- stronger than the bond between the valence electron and the parent atom
- can go into *free state* when enough kinetic energy is applied
- *intrinsic*: any semiconductor material that has been carefully refined to reduce the number of impurities to a very low level

Intrinsic Carriers and Mobility Factor

Semiconductor	n_i Intrinsic Carriers (per cm^3)
GaAs	1.7×10^6
Si	1.5×10^{10}
Ge	2.5×10^{13}

Semiconductor	μ_n Relative Mobility Factor ($cm^2/V \cdot s$)
Si	1500
Ge	3900
GaAs	8500

- doping : changing the characteristic of the material by adding proper type of impurity in controlled amounts

Intrinsic Carriers and Mobility Factor

- *doping* : changing the characteristic of the material by adding proper type of impurity in controlled amounts
- reaction to heat: semiconductors have *negative temperature coefficient* (i.e. more valence electrons can break the covalent bond and contribute to the number of free carriers increasing the conductivity)
- note that, conductors have positive temperature coeffiecient (i.e. Increased resistance due to vibrating electrons)

Energy Levels

- specific energy level associated with each shell and orbiting electron
- discrete energy levels
- the farther an electron is from the nucleus, the higher the energy level
- any electron that has left its parent atom has an energy state higher than any electron in the atomic structure
- conduction band, valence band, energy gaps

Extrinsic Materials

- *extrinsic material*: a semiconductor material that has been subjected to doping.

n-Type

- silicon or germanium base
- pentavalent impurity elements (eg. Sb, Ar, Ph)
- 4 covalent bonds, 5th electron usassociated with any covalent bond
- donor atoms
- still neural!!!
- majority carrier is the electron

p-Type

- silicon or germanium base
- tetravalent impurity elements (eg. B, Ga, In)
- 3 covalent bonds, one vacancy → hole
- acceptor atoms
- still neural!!!
- majority carrier is the hole

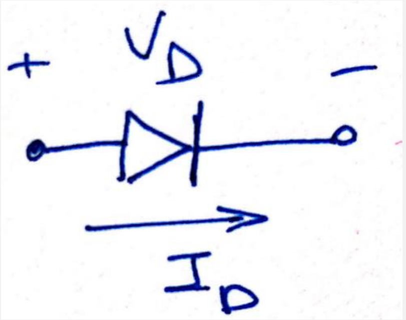
electron flow vs hole flow

conventional flow → direction of the hole flow

Semiconductor Diodes

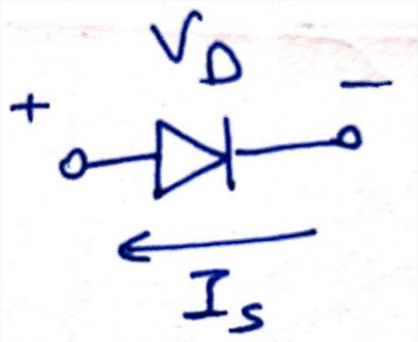
- bring n-type and p-type materials together
- a two terminal device is formed
- a depletion region is formed near the junction

No Applied Bias



- in the absence of an applied bias voltage, the net flow of charge in any one direction for a semiconductor diode is zero

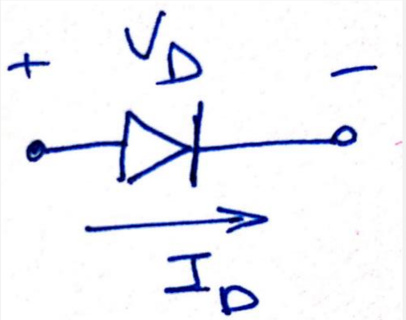
Reverse-Bias Condition



- An external voltage is applied across the junction such that the positive terminal is connected to the n-type material and the negative terminal is connected to the p-type material.
- The current that exists under reverse-bias conditions is called the *reverse saturation current* and is represented by I_S.
- Reverse saturation current is in the order of a few microamperes and does not change significanty with the increase in reverse-bias potential.

Forward-Bias Condition

- Apply positive potential to the p-type material and negative potential to the n-type material.



- The width of the depletion region is reduced.
- The voltage rises quickly and stays at around a value less than 1V and the current value depends on the applied external voltage and other circuit parameters.

Forward-Bias Condition

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the p-n junction. This energy comes from the external voltage applied across the diode.

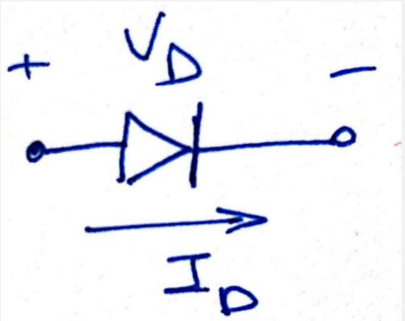
The forward bias voltage required for a:

gallium arsenide diode $\cong$ 1.2 V

silicon diode $\cong$ 0.7 V

germanium diode $\cong$ 0.3 V

Ideal Diode Characteristics



A diode ideally conducts in only one direction.

Conduction Region

The voltage across the diode is 0 V
The current is infinite
The diode acts like a short

Non-Conduction Region

All of the voltage is across the diode
The current is 0 A
The diode acts like open

Diode Characteristics

Shockley's equation

$$I_D = I_S\left(e^{V_D/nV_T} - 1\right)\ \text{(A)}$$

I_S : reverse saturation current

V_D : applied forward-bias voltge across the diode

n : ideality factor, which is a function of the operating conditions and physical construction (between 1 and 2)

V_T : thermal voltage

$$V_T = \frac{kT_K}{q}\ \text{(V)}$$

k : Boltzman's constant = 1.38×10^{-23} J/K

T_K : absolute temperature in kelvins = 273 + the temp in C°

q : magnitude of electronic charge = 1.6×10^{-19} C