Semiconductors, Diodes, Shockley's Equation

06 September 2023 10:47

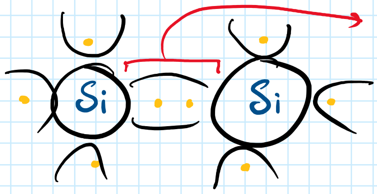
SEMICONDUCTORS

- Neither fully a conductor nor an insulator

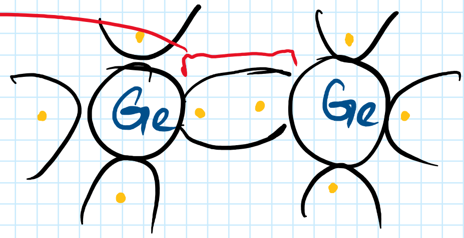
Looking at two examples,

Si
- 4 valence electrons

Ge
- 4 valence electrons



covalent bonding



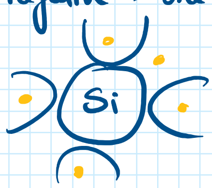
TYPES OF SEMICONDUCTORS

Intrinsic : Pure semiconductor, no impurities

Extrinsic : External impurities are added

n-type

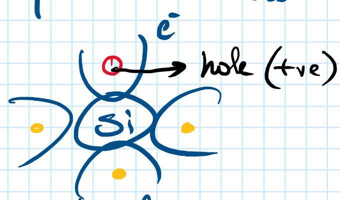
- pentavalent impurity added { antimony, arsenic phosphorous
- n → negative → one extra e^-



- majority charge carriers: electrons

p-type

- trivalent impurity added { Boron, gallium, indium
- p → positive → one less e^-

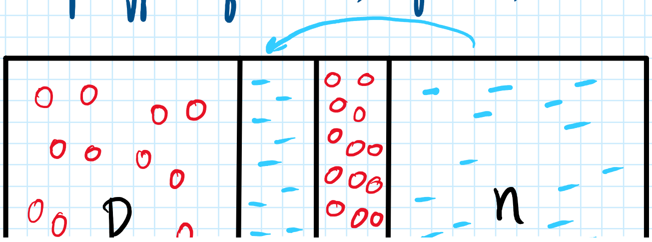


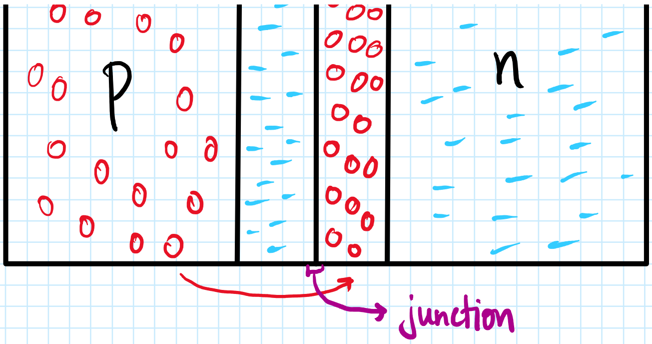
- majority charge carriers: holes/voids

DIODES

- has anode, cathode] → 2 electrodes
- combination of p-type, n-type; forms a depletion region at their junction
- allows current flow in one direction only (forward bias)

HW: List of types of diodes, symbols, characteristics





P-N JUNCTION DIODE

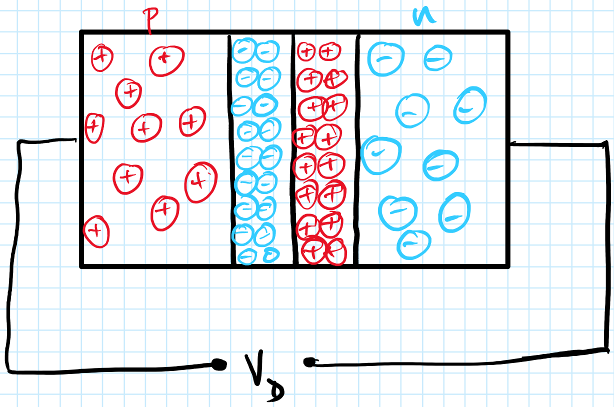
- After joining p-type, n-type, electrons from n-type near junction diffuse into p-region.
- IIIly, holes from p move into n region.
- This forms the depletion region.

→ creates a potential barrier, which has to be overcome by an external voltage source for flow of charges

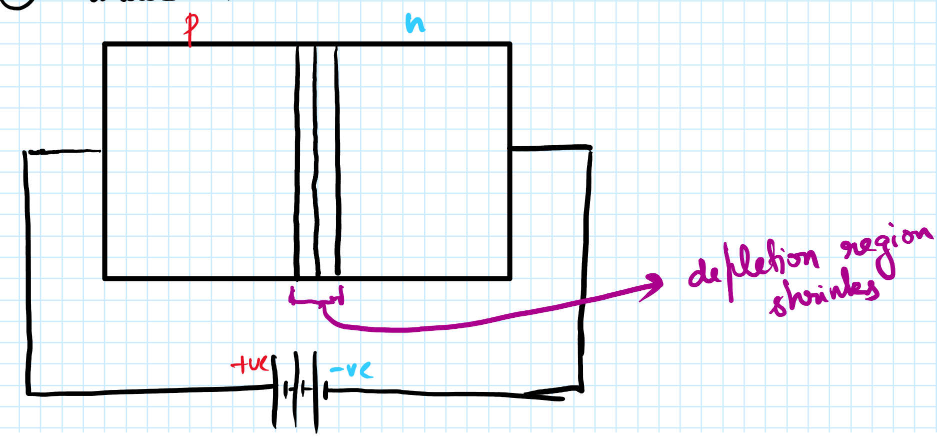
DIODE BIASING

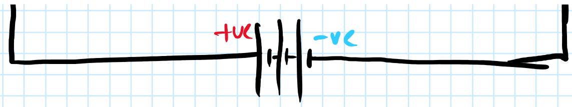
→ process of applying external voltage

① No bias

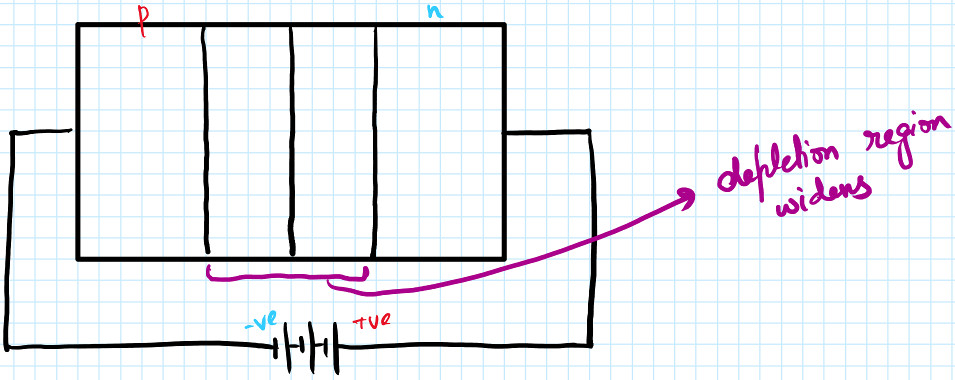


② Forward bias

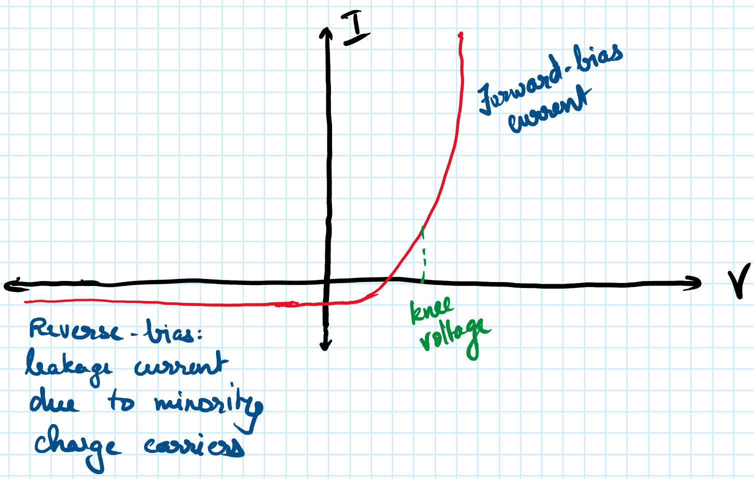




③ Reverse bias



FORWARD & REVERSE CHARACTERISTICS



Forward characteristics

- Knee voltage / cut in voltage: Forward voltage at which conduction happens and current starts rising rapidly
- Conduction does not occur on a significant scale until knee voltage is reached.
- Knee voltage for:
  - Si → 0.7V   GaAs → 1.2 V
  - Ge → 0.3 V
- Forward current rating: Current that flows in forward direction when diode is in forward bias
- Max. power dissipation: Max. power a diode can dissipate without damaging the device itself

Reverse characteristics

- Reverse saturation current: Reverse current caused by diffusion of minority charge carriers.
  Also called leakage current.

Also called leakage current.

- **Reverse breakdown voltage**: If large enough negative potential is applied, it will allow current flow in the reverse direction.

- **Peak inverse voltage rating**: Maximum voltage a diode can withstand in reverse bias condition before break down.

SHOCKLEY'S CURRENT EQUATION / DIODE EQUATION

to find current through diode at a certain temperature

- When V_D is negative

$$\boxed{I_D \sim I_S}$$

- When V_D is positive

$$\boxed{I_D \sim I_S\, e^{\frac{qV_D}{nkT}}}$$

In general,

$$\boxed{\underbrace{I_D}_{\text{diode current}} = \underbrace{I_S}_{\text{saturation current}}\left[e^{\frac{qV_D}{nkT}} - 1\right]}$$

q: charge on electron = 1.6×10^{-19} C

V_D: diode voltage

T: Temperature in Kelvin

k: Boltzmann's constant
$k = 1.380 \times 10^{-23}$ J/K

n: ideality factor
$n = 1$ → indirect semiconductors → Si, Ge
$n = 2$ → direct " → GaAs, InP

> **NOTE: Direct and indirect band gap semiconductors**
>
> CBM → conduction band minimum → min. energy e^- in conduction band can have
>
> VBM → valence band maximum → max. energy e^- in valence band can have
>
> k → momentum of e^- in crystal lattice
>
> Direct: CBM and VBM both occur at same k. Eg: LEDs, lasers
>
> Indirect: CBM and VBM occur at different k. Eg: Transistors

Here we have

Thermal voltage $= V_{th} = \dfrac{kT}{q}$

> **NOTE: What is thermal voltage?**
> Voltage produced within the p-n junction diode due to the action of temperature.

Substituting this in our equation, we get

$$\boxed{I_D = I_S\left[e^{\frac{V_D}{nV_{th}}} - 1\right]}$$

At $T = 300$ K,

$$V_{th} = \frac{kT}{q} = \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}$$

$$V_{th} = \frac{}{q} = \frac{}{1.6 \times 10^{-19}}$$

$$\boxed{[V_{th}]_{300K} = 0.0258\ V = 25.8\ mV \approx 26\ mV}$$ } V_{th} at room temperature

NUMERICAL

① Calculate forward bias current of Si diode when forward bias voltage of 0.4 V is applied, the reverse saturation current is 1.17×10^{-9} A and thermal voltage is 25.2 mV.

Soln.

$$I_s = I_D \left[e^{\frac{V_d}{nV_{th}}} - 1 \right]$$

Substituting,

$$I_s = 1.17 \times 10^{-9} \left[e^{\frac{0.4}{(1)(0.0252)}} - 1 \right]$$

$$I_s = 9.15 \times 10^{-3}\ A$$