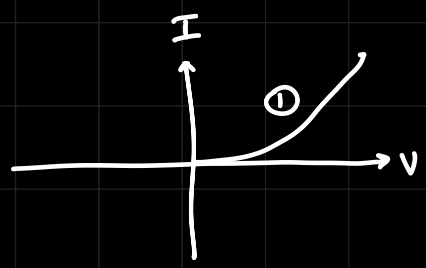
1st charge transport mechanism

$$\bar{v}_h = \mu_p \bar{E} \quad , \quad \bar{v}_e = \mu_n \bar{E}$$

* primary transport : drift
secondary transport : diffusion

→ tunnelling is also a transport mechanism in case of highly doped junctions
→ Thermionic

PN :



① $I = I_s e^{\frac{eV}{k_b T n}}$ ↳ non ideality factor

DRIFT TRANSPORT MECHANISM

Spintronics : spin motion related to electrons

movement of charges because of an electric field ≡ DRIFT

drift velocity: $\bar{V}_h = \mu_p \bar{E}$ $\quad \bar{V}_e = -\mu_n \bar{E}$ → mobility

DRUDE model

when e^- move, we can visualize interaction as that of a gas i.e. very less

τ { relaxation time approximation : time btw 2 successive e^- collisions
OR mean free time
OR collision time }

mean free path (25-30nm for Si/Ge) = same thing but the distance between 2 successive collisions

τ is independent of e^- position and velocity

~~ballistic missile : travels without deviation~~

ballistic motion : e^- travelling through the mean free path without deviation

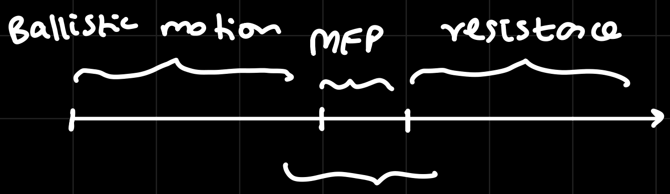
but if e^- goes beyond mean free path, there are collisions and hence resistance.

probability that an e^- faces collision per time $\rightarrow \frac{1}{\tau}$

within small time, $\frac{dt}{\tau}$

Quasi - Ballistic Motion

↳ near the mean free path, midway between collisions and no - collisions



$$m_e \frac{d\bar{v}}{dt} = -e\bar{E}$$

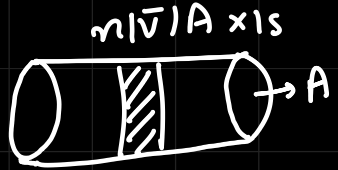
integration ↳

$$\bar{v}(t) = \frac{-e\bar{E}t}{m_e}$$

drift velocity

mean free time

$$\boxed{\bar{v} = \frac{-e\bar{E}\tau}{m_e}} \quad (1)$$



(e-) Charges passing in unit time : $n|v|A$

current : $-en|v|A$

current density : $J = n\bar{v}(-e)$

from (1) → $\bar{J} = \underbrace{\frac{ne^2\tau}{m^*_e}}_{\sigma} \bar{E}$

σ conductivity

$$\bar{J} = \sigma\bar{E}$$

$$J = \sigma E = \frac{E}{\rho}$$

$$\sigma = \frac{ne^2\tau}{m_e} = n\mu e$$

\# of e⁻ → n; charge → e; μ → mobility

resistivity, $\rho = \frac{m_e}{ne^2\tau}$

mobility = avg of relaxation time τ

$$\mu = \frac{e\tau}{m_e^*}$$

$$|\bar{v}| = \mu|\bar{E}|$$

→ $\sigma = n\mu e$

μ unit : cm^2/Vs (V → volt, s → second)

$$\mu = \frac{e\tau}{m^*}$$

{ we can find n from m^* }

{ carrier density $\propto \frac{1}{\text{mobility}}$ } we need to balance

$m^* \downarrow\downarrow \rightarrow \mu\uparrow$ but $m^* \propto$ curvature and so DOS goes down

Si balances μ and carrier density well and hence $I\uparrow$

↳ hence prefered

$m_l = 0.98 m_0$ } GaAs and Si { $m_* = 0.15 m_0$
$m_t = 0.19 m_0$

not much difference
BUT

$\mu_{GaAs} = 5000 \, cm^2/Vs$
$\mu_{Si} = 1200 \, cm^2/Vs$

So, τ plays a major role

$J_n = \mu_n \bar{E} \cdot n \cdot q$
$J_{total} = q(\mu_n n + \mu_p p) \bar{E}$

note: $\mu_{n_{Si}} = 1200 \, cm^2/Vs$ (e^-)

$\mu_{p_{Si}} = 600 \, cm^2/Vs$ (hole)

because of difference in effective mass
($m_e >> m_h$)

NMOS : MOSFET with n channel (e^-)
PMOS: p channel (holes)

we take size of PMOS as double of NMOS
because of μ_p and μ_n ($\mu_p \approx \frac{1}{2} \mu_n$)
to balance current from PMOS & NMOS
($m_* \rightarrow \mu \rightarrow \sigma \rightarrow J \rightarrow I$)

SCATTERING MECHANISM IN A SC DEVICE

→ Matthiessen's Rule : Resistivity is the sum of all individual resistivity in the system

↓

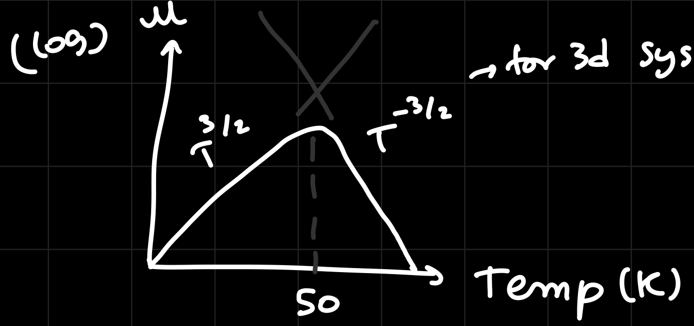
conductivity $\sigma = \frac{1}{\rho}$

$$\frac{1}{\tau} = \frac{1}{\tau_{phonon}} + \frac{1}{\tau_{impurity}}$$

$$\frac{1}{\mu} = \frac{1}{\mu_{phonon}} + \frac{1}{\mu_{impurity}}$$

Scattering mechanisms

- ↳ Defect
  - ↳ Crystal
  - ↳ Impurity
    - ↳ Neutral
    - ↳ Ionized
  - ↳ Alloy
- ↳ carrier – carrier
- ↳ Lattice
  - ↳ Intravalley
    - ↳ Acoustic
      - ↳ Deformation Potential
      - ↳ Piezo electric
    - ↳ Optical
      - ↳ Non Polar
      - ↳ Polar
  - ↳ Intervalley
    - ↳ Acoustic / optical



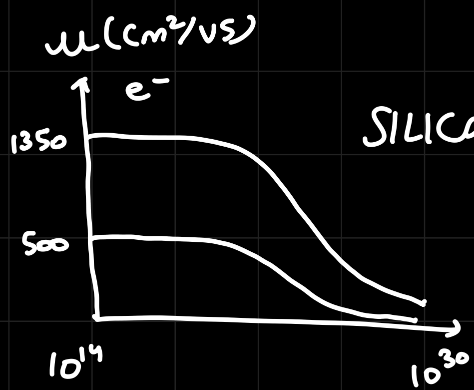
→ for 3d system

impurity scattering dominates at low temps ← related to doping

lattice scattering dominates at high temps → remember phonon generation

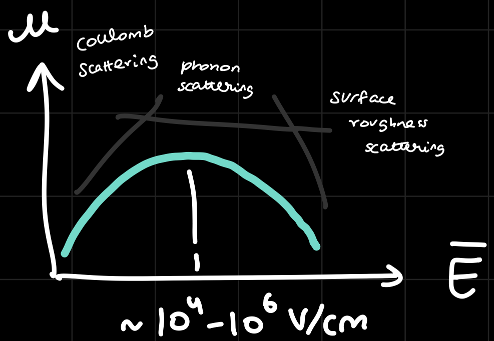
temp ↑, vibrations ↑, scattering ↑, μ ↓

below 50K, lattice vibrations are very small



SILICON

doping conc
↓
carrier density ↑
but μ ↓
tradeoff ↓
because τ ↓↓
(more carriers in limited space)



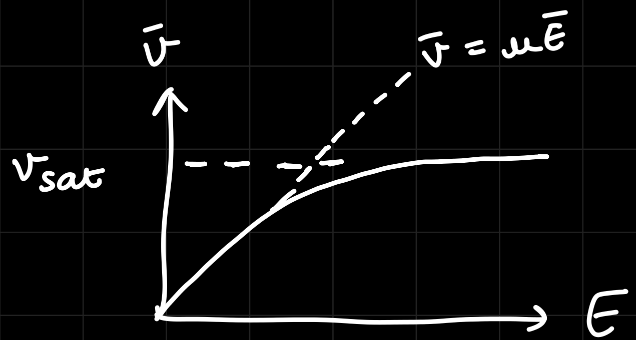
2

$V_t = \mu \bar{E}$

but practically, v does not increase linearly with $\bar{E}$ since μ does not linearly increase as $\bar{E}\uparrow$ in 2

$$\boxed{v = \frac{\mu_0}{1 + \frac{\mu_0 E}{v_{sat}}} E}$$

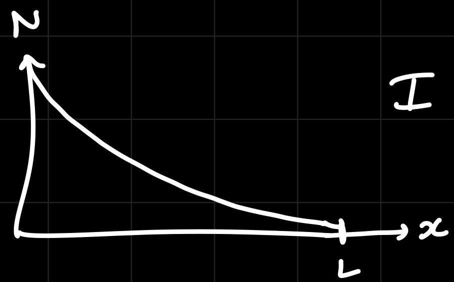
Velocity saturation



Second Transport Mechanism : Diffusion

$$J_n = qD_n \frac{dn}{dx} \quad , \quad J_p = -qD_p \frac{dp}{dx}$$

if current density is non linear, urrent will also be non-linear



I will also be exponential

forward bias: diffusion (major)

Reverse bias : drift (major)

$$\frac{D}{\mu} = \frac{KT}{q}$$

Einstein's Relation