Sumedh

- Topics

1. Elec Measurements
2. 2 probe Method
3. 4 probe Collinear
4. 4 probe van der Pauw
5. Hall effect
6. Hot probe for semicon thin film
7. Capacitive – Voltage Measurement
8. P-N (I-V)
9. TCAD
10. Boltzman transport eq
11. MC

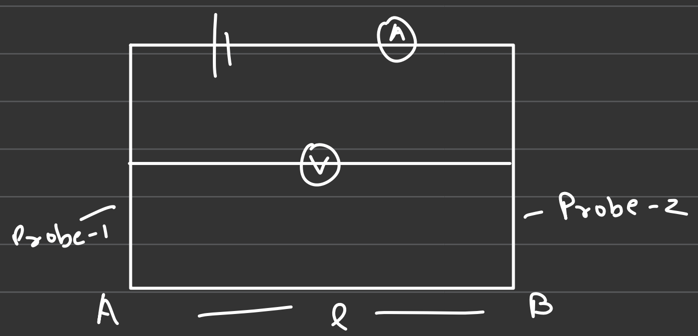
- Two probe method

Method used to measure resistivity

known

$$R = \frac{\rho \, l}{A}$$

unknown



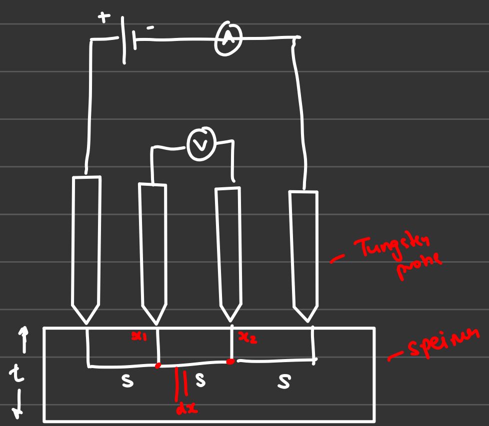
$$\rho = \frac{R A}{l}$$

$$\rho = \frac{V}{I} \times \frac{A}{L}$$

Two-probe method: (disadvantages)

❖ Error due to contact resistance of the measuring leads,
❖ Materials having random shapes,
❖ Soldering of the test leads on some materials would be difficult,
❖ Heating of the leads during soldering may inject additional impurities in materials such as semiconductors and thereby affecting the intrinsic electrical resistivity largely.

- **Four probe Method**



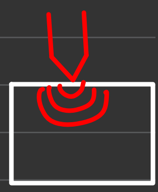
$$R = \frac{\rho l}{A}$$

$$R = \frac{\rho x}{A}$$

$$dR = \frac{\rho\, dx}{A}$$

Note :-

For Area



$\therefore\ A = 2\pi x^2$

$$\int_{x_1}^{x_2} dR = \int_{x_1}^{x_2} \rho \left(\frac{dx}{A}\right)$$

$$\therefore\ R = \rho \int_{x_1}^{x_2} \frac{dx}{A}$$

Case - 1 $\quad t >> s$

$$R = \rho \int_{x_1}^{x_2} \frac{dx}{A}$$

$$= \rho \int_{x_1}^{x_2} \frac{dx}{2\pi x^2}$$

$$= \frac{\rho}{2\pi} \int_{x_1}^{x_2} \frac{dx}{x^2}$$

$$= \frac{\rho}{2\pi} \left[-\frac{1}{x}\right]_{x_1}^{x_2}$$

$$= \frac{\rho}{2\pi} \left[-\frac{1}{x}\right]_{s}^{2s}$$

$$= \frac{\rho}{2\pi} \left[\frac{-1+2}{2s}\right]$$

$$\therefore\ R = \frac{\rho}{2\pi s}$$

Ohm's law, $V = IR$

$$R = \frac{V}{I}$$

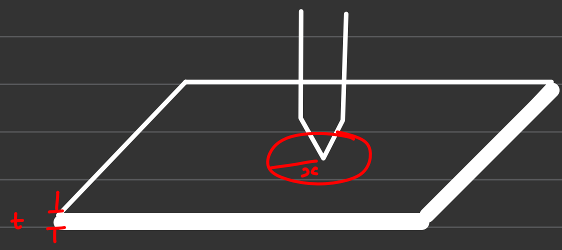
$$R = \frac{V}{2I}$$

curr passing frm two probes

$$\therefore\ \frac{\rho}{4\pi s} = \frac{V}{2I}$$

$$\boxed{\rho = 2\pi s \left(\frac{V}{I}\right)}$$

Case - 2 $t << s$



$2\pi x \cdot t = A$

$$R = \rho \int_{x_1}^{x_2} \frac{dx}{A}$$

$$= \rho \int_{x}^{x_1} \frac{dx}{2\pi x \cdot t}$$

$$= \frac{\rho}{2\pi t} \int_{s}^{2s} \frac{dx}{x}$$

$$= \frac{\rho}{2\pi t} \left[\ln x \right]_{s}^{2s}$$

$$= \frac{\rho}{2\pi t} \ln(2s) - \ln s$$

$$= \frac{\rho}{2\pi t} \frac{\ln(2s)}{s}$$

$$R = \frac{\rho \ln 2}{2\pi t}$$

Ohm's law , $V = IR$

$$R = \frac{V}{I}$$

$$R = \frac{V}{2I}$$

$$\frac{\rho}{2\pi t} \ln 2 = \frac{V}{2I}$$

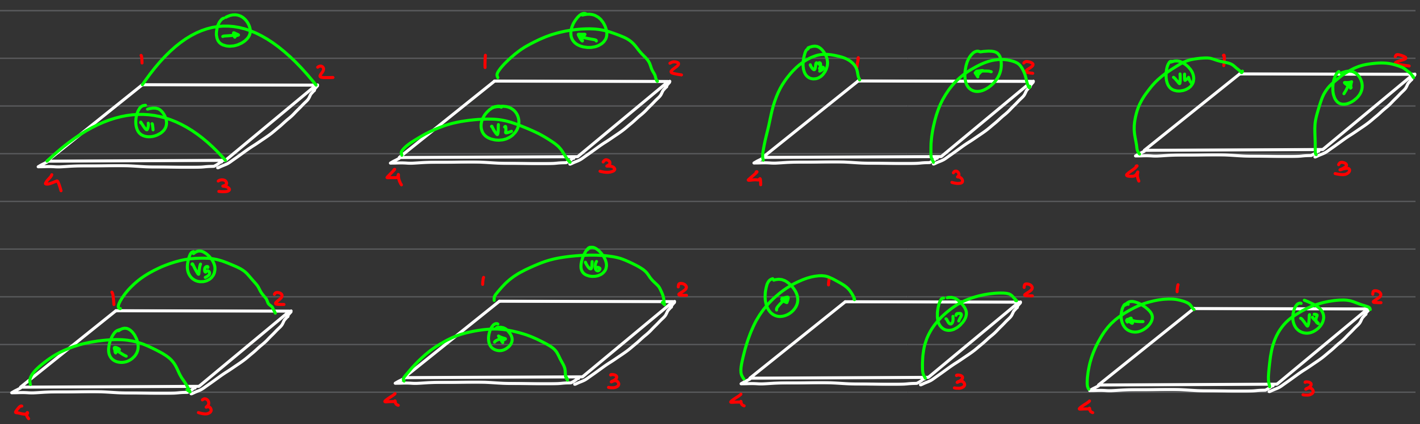
$$\boxed{\rho = \frac{\pi t}{\ln 2} \left(\frac{V}{I} \right)}$$

• Van der Pauw Method

Used to measure resistivity and hall coefficient of sample conditions :-

- must have flat shape of uniform thickness
- must not have isolated holes
- must be homogeneous , isotropic & symmetrical
- All four contacts must be located at edges
- Area of contact should be less that area of sample
- Thickness << len , width

Restivity can be determined from total of 8 measurements around periphery of the sample



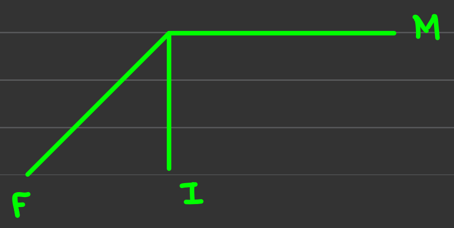
$$\rho_A = \frac{\pi}{\ln 2} f_A t_s \frac{(V_1 - V_2 + V_3 - V_4)}{4I}$$

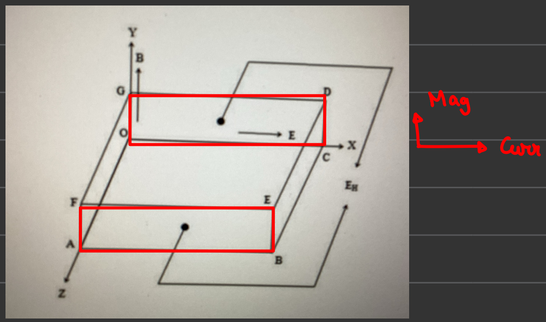
$$\rho_B = \frac{\pi}{\ln 2} f_B t_s \frac{(V_5 - V_6 + V_7 - V_8)}{4I}$$

• Hall effect

When a conductor (metal / semi) carrying curr placed in trans Mag fld , elec fld produce inside conductor and direction $\perp$ to curr & mag

This is called hall effect





Case - 1 : N-type Semicon

- ∵ N-type , maj charge carriers are e^-s
- current flows through OX , ∴ e- thru XO
- if Vel of e = v ; charge = -e

  ∴ F due to Mag fld = - Bev along OZ
- e^-s deflect and accumulate at ABEF
- ABEF is (-ve) , OCDG is (+ve)
- ΔV formed causing elec fld E_H
- Force rises $-eE_H$ in - Z

at Eq^{br} , $eE_H = Bev$

$$E_H = Bv$$

also , $J = -nev$

$$v = \frac{-J}{ne}$$

$$E_H = \frac{-BJ}{ne}$$

we know , Hall effect is R_H in terms of current & density

$$E_H = R_H BJ$$

$$R_H = \frac{E_H}{BJ}$$

$$R_H = \frac{BJ}{-ne\,BJ} = \frac{-1}{ne}$$

Case - 2 : P-type semi

- if P-type, maj charge cars are holes ie (+ve)
- ∴ holes move in curr directn OX
- charge on hole +e, F = Bev at OZ
- $R_H = 1/pe$

Determination

$E_H = V_H / \omega$ widh

$R_H = E_H / BJ$

$R_H = \frac{V_H}{\omega BJ}$

$V_H = R_H \omega BJ$

$J = I / A$

$= \frac{I}{\omega t}$

$\therefore V_H = R_H \omega BJ / \omega t$

$$\boxed{V_H = \frac{R_H I B}{t} \qquad R_H = \frac{V_H t}{IB}}$$

for n-type : $\mu_e = -\sigma_n R_H$

$\mu_p = \sigma_p R_H$

Applications

i) Determine type of semi

in N : R_H = -ve

P = +ve

ii) Carrier Conc

$n = 1/eR_H$ / $p = 1/eR_H$ once R_H measur

ii) Mobility

$\mu_e = -\sigma_n R_H$
$\mu_p = \sigma_p R_H$

iv) Mag flux

$R_H = \frac{V_H t}{BI}$

$B = V_H t / R_H I$

- Hot Probe method for semi thin film

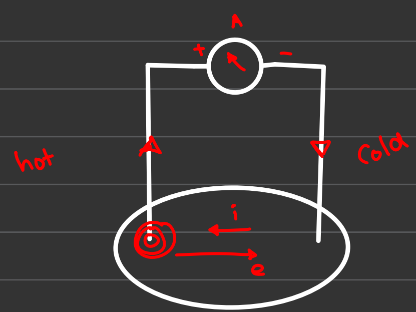
Method used to determine the doping of specimen

Principle : A conventional hot probe experiment enables a simple and efficient way to distinguish b/w n-type & P-type using a hot probe and standard multimeter

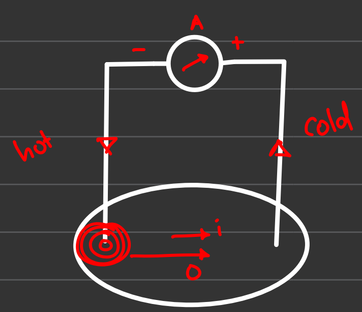
for n-type : +ve voltage
for p-type : -ve voltage

Construction :

i) A couple of cold & hot probe attached to a semi film
ii) Hot probe to +ve terminal & Cold (-ve) of the multimeter
iii) The thermally excited majority free charge cars go from hot to cold
iv) A buit in $\bar{E}$ is created b/w hot & cold probes which prevents diffusion process up to a hot.
v) Recombination of excited electrons takes place



(N - type)

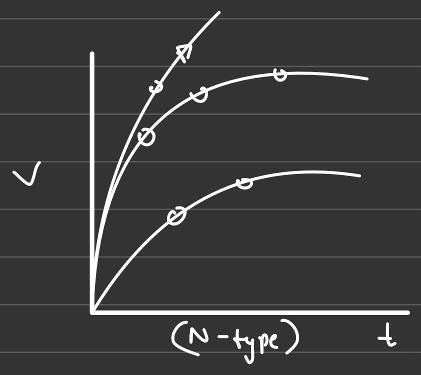


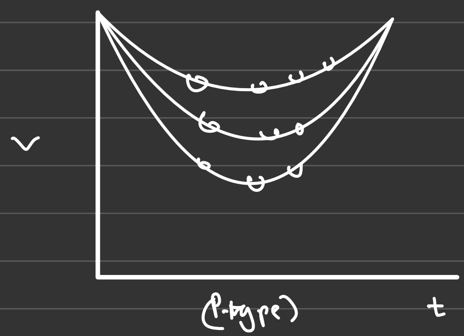
(P-type)

This is described by continuity & poisson's eq^n

$$\nabla J + \frac{\partial Q}{\partial t} = U$$

$$\nabla E = \frac{Q}{\varepsilon_0 \varepsilon_r}$$





- **TCAD**

It is a computer simulation technique used to design, optimise and analyse semi devices and processes.

It's a branch of electron design automation (EDA)

Objectives :

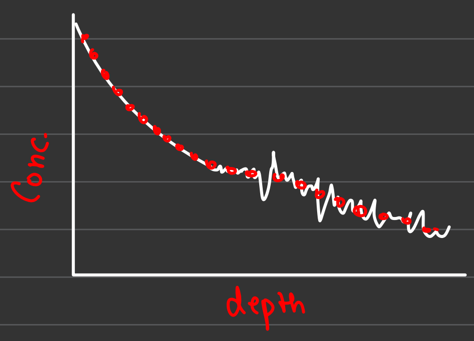
- Understand relationships b/w various potentials & energies used to understand device control
- Under how fundamentals paras vary is semi (band gap, dielectric const)
- Understand how biasing affects various potentials & energies at device terminal

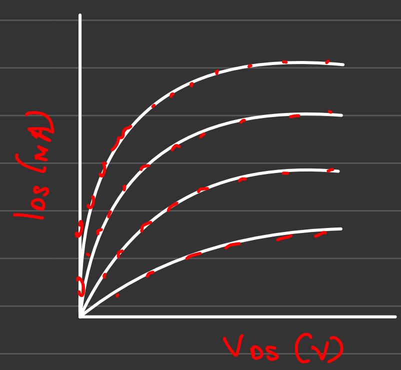
Types :

Process TCAD	Device TCAD
i) Modeling of fabrication / semi manufacturing steps like diffusion, oxidation, mech. Stress on implantation, litho-graphy.	i) Modelling of device operation optical, electrical, mech. behaviour of semi (MOSFET, BJT)
ii) Modeling of physical principles of manufacturing Calibration of models needs expensive exps	ii) Physical principles at the basis of carrier transport & optical generation in semi devices.

iii) Stimulate doping profiles obtained by specific processing techniques

iii) Stimulate output characteristics of MOSFET device





Advantages

i) Helpful when hands-on-calculations are complicated

ii) helps to make predictions (scaling & new device components)

iii) To get insights as no real exp needed

iv) reduce development costs, time of manufacturing cycle

v) quickly screen technological option

- BTE

It depicts how the probablity distribution function of a system of particle changes as a resut of external forces, collisions & interactions.

Under no force (Eq^{br}) the charge cars obeys the fermi-dirac stats

The func after, change depends on time, space & momentum

∵ no of e's is conserved, integral remain is const, if the time derivative is 0

$$\frac{df(\bar{r}, \bar{k}, t)}{dt} = 0$$

$$= \frac{\partial f}{\partial x}\frac{dx}{dt} + \frac{\partial f}{\partial y}\frac{dy}{dt} + \frac{\partial f}{\partial z}\frac{dz}{dt} + \frac{\partial f}{\partial k_x}\frac{dk_x}{dt} + \frac{\partial f}{\partial k_y}\frac{dk_y}{dt} + \frac{\partial f}{\partial k_z}\frac{dk_z}{dt} + \frac{df}{dt}$$

$$\therefore \frac{df}{dt} = -\left(\qquad \right)$$

$$\frac{df}{dt} = -\left[\frac{\partial f}{\partial x}(v_x) + \frac{\partial f}{\partial y}(v_y) + \frac{\partial f}{\partial z}(v_z)\right]$$

$$- \left[\frac{\partial f}{\partial k_x}(F_x) + \frac{\partial f}{\partial k_y}(F_y) + \frac{\partial f}{\partial k_z}(F_z)\right]$$

let $\nabla_r = \frac{\partial}{\partial x}\hat{i} + \frac{\partial}{\partial y}\hat{j} + \frac{\partial}{\partial z}\hat{k}$

$$V = v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$$

$$\therefore (\nabla_r f).V = \frac{\partial f}{\partial x}(v_x) + \frac{\partial f}{\partial y}(v_y) + \frac{\partial f}{\partial z}(v_z)$$

Simi^{lly},

$$(\nabla_k f).F = \frac{\partial f}{\partial k_x}(F_x) + \frac{\partial f}{\partial k_y}(F_y) + \frac{\partial f}{\partial k_z}(F_z)$$

$$\frac{df}{dt} = -\left[(\nabla_r f).V\right] - \left[(\nabla_k f).F\right]$$

$$\frac{df}{dt}_{(force)} = -\frac{dr}{dt}(\nabla_r f) - \frac{dk}{dt}(\nabla_k f)$$

We know that, $F_{ext} = \hbar\frac{dk}{dt}$

$$\therefore \frac{dk}{dt} = \frac{F_{ext}}{\hbar}$$

also $\frac{df}{dt}(\text{total}) = \frac{df}{dt}(\text{force}) + \frac{df}{dt}(\text{collision})$

$$\therefore \frac{df}{dt}_{(total)} = -\frac{dr}{dt}(\nabla_r f) - \frac{dk}{dt}(\nabla_r f) + \frac{df}{dt}_{(collision)}$$

$$\frac{df}{dt}_{(total)} = -v(\nabla_r f) - \frac{F_{ext}}{\hbar}(\nabla_r f) + \frac{df}{dt}_{(collision)}$$

- **Monte Carlo Method**

Developed in 1940s, use to solve problems & approx. the behaviour of a system using random sampling

eg Establishing value of 'π'

area = πr^2

for quadr circ = $\frac{\pi r^2}{4}$

$= \frac{\pi}{4}$ (r=1

Acc. to Monte Carlo

$$\frac{\pi}{4} = \frac{\text{no. of pts within } x^2+y^2 \leq 1}{\text{Total no of pts gen.}}$$

$$\pi = 4 \times \text{no. of points with } \frac{x^2+y^2 \leq 1}{\text{totl pts}}$$

$$= \frac{8}{10} = 3.2 \approx 3.14$$

MC as a solⁿ to BTE:

Solving it analytically can be difficult. MC uses random sampling (input variables)

Steps

- the system is stimulated by large no of particles on initial condⁿ i.e positⁿ & energy
- particles are tracked as they move thru the material undergoing interactions
- the outcome is determined by random sampling a set of prob. distributⁿ
- From these satistical quantities, energy distribution of particles or scattering of the material can be calculated
- These quantities is used to solve BTE & predict behaviour of the material