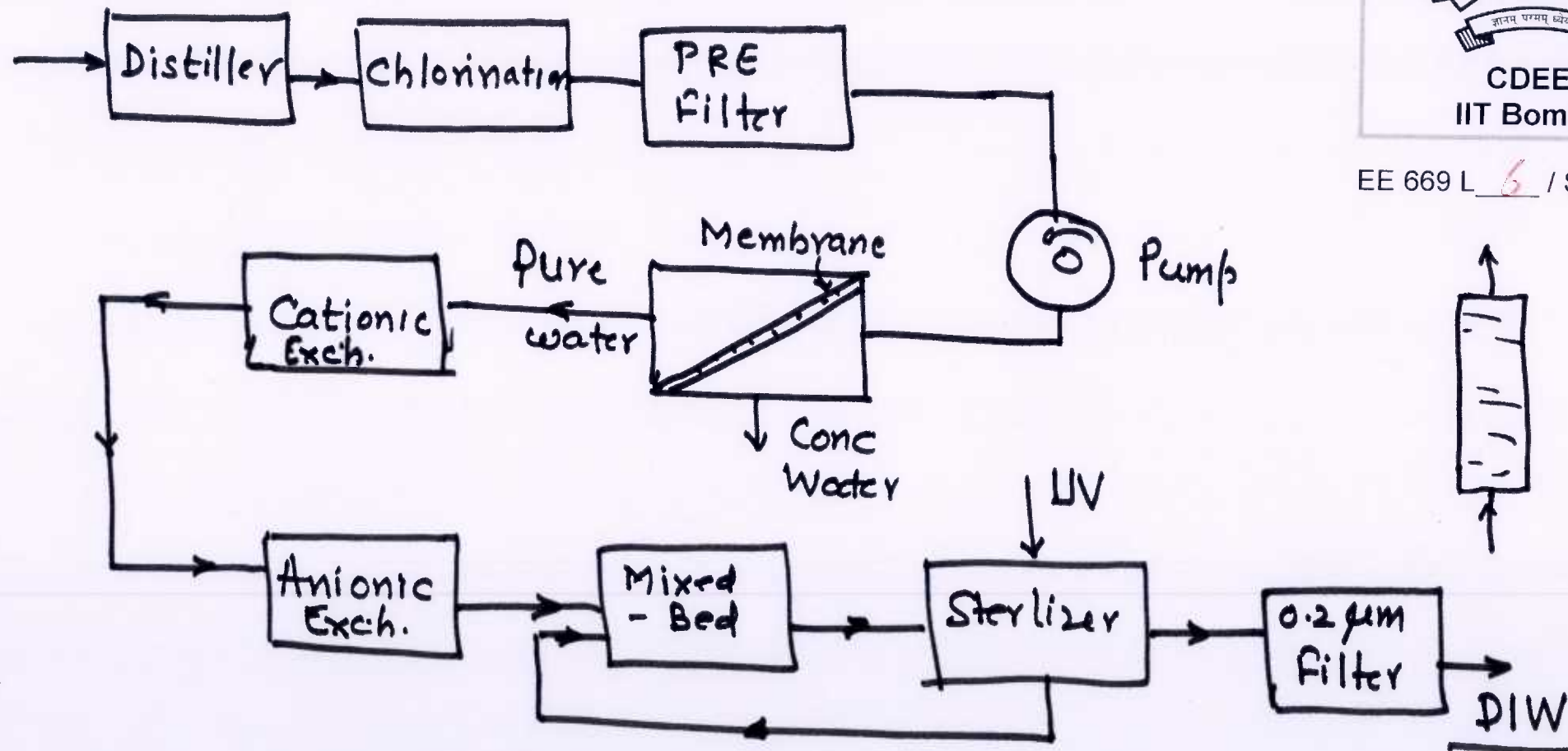


RO System



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— Accessories —
Tubing : Stainless Steel and Teflon

Equipment : 1. Quartzware 2. Teflonware
3. Polypropylene 4. SS & Tweezers

Chemicals : 1. Organic 2. Inorganic (Acids & Base)
TCE HCl, HF, H₂SO₄, HNO₃
TCA NH₄OH, H₂O₂, H₃PO₄, NH₄F
Acetone
Benzene
Photoresists

All chemicals should be MOS Electronic Grade

Gases : — O₂, O₃, N₂, H₂, HCl, TCA, N₂O, NH₃, Argon
Phosphene PH₃, AsH₃, B₂H₆, Silane (SiH₄), SiCl₄, SiHCl₃
CH₃Cl, C₂H₂Cl₂, F, CF₄, S₂F₆



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— DIFFUSION —

Impurity Incorporation in Semiconductors



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All Semiconductor Devices use multiple impurity regions. Eg. Diode has two regions p type and n-type. We start with say n-type region doped with n-type impurities say Phosphorous (or Arsenic). This can be starting wafer from Crystal Growth. To make a diode, we must introduce P-type impurities (Boron) in this Substrate. Introduction of Impurities should be controllable both in total Impurities needed and depth to which these impurities should penetrate.

Impurities can be incorporated in Silicon Crystal by following processes



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1. During Cz crystal growth, we add fixed amount of desired impurities in the Melt.
2. ~~During~~ During FZ crystal growth, crystal can be doped by zone-leveling technique.
3. In Epitaxial growth, impurities get uniformly distributed in growth process.
4. Solid State Diffusion is major source of impurity incorporation.
5. Ion Implantation is the most popular technique of impurity incorporation.

Epitaxial Growth

EPI-layer on Si

Substrate Si / or any



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However more important issue is to know how these impurities transport in crystalline material. This process of transport is known as 'Diffusion'. Any time-temp. cycle sees impurities - diffusion in space & the Crystal.



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Definition: Diffusion is the Process by which atoms move in Crystal Lattice. The motion of an Impurity atom in a Lattice, takes place in series of Random Jump (3D process). The net jump position is the Statistical Average.

Hence for controlled and specific impurity motion, one must study "Physics of Diffusion". Please note that even Silicon atoms diffuse in Silicon (By diffusion) and the process is called "Self Diffusion".

How do Impurities influence electrical behavior of Semiconductor (devices/circuits) ??

Electrical Properties are influenced by :

- (a) Type of Majority Carriers
- (b) Carrier Concentration
- (c) Carrier Conc. Gradients
- (d) Carrier Life time
- (e) Internal Electrical Field

Impurities used in Semiconductor Devices, show energy level /levels in Semiconductor Bandgap.

N-type Impurities show energy level close to (but below) the conduction band edge; while p-type show energy level close to valance-band edge.



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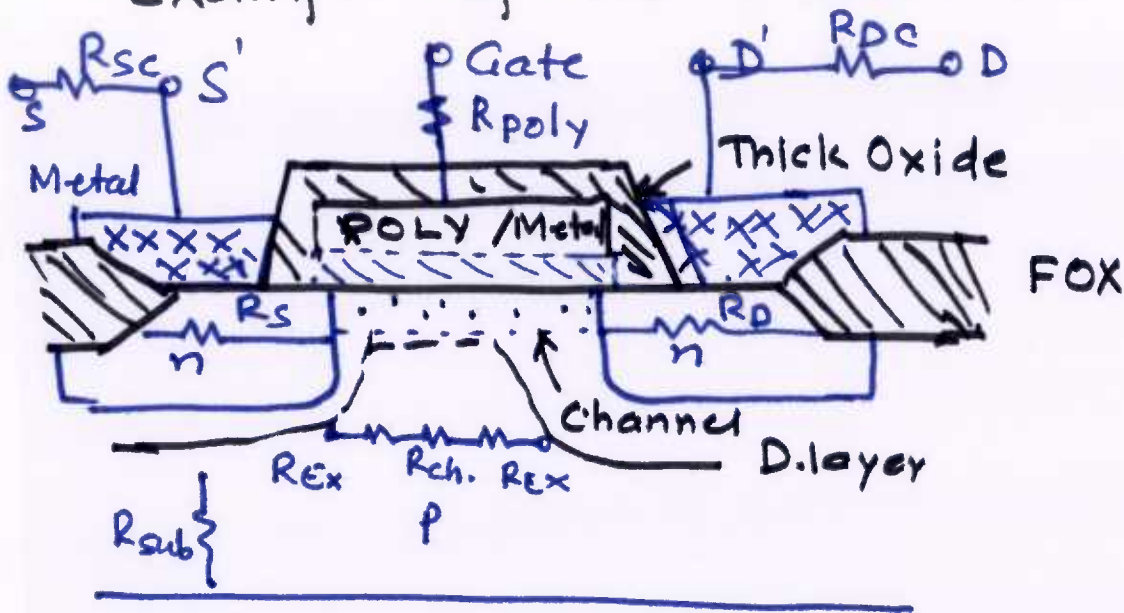
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Example of MOS Transistor



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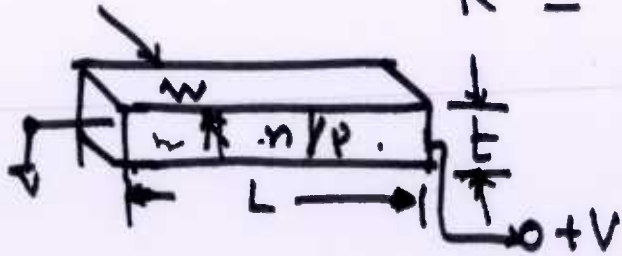
- (i) Source & Drain regions are created in Substrate with opposite doping.
- (ii) Doped Poly gives metal like resistivity for Gate.
- (iii) Parasitics like R_s , R_d , R_{ext} , R_{sc} , R_{pc} impact the I_{dsat} , the Drive Current

(iv) Short-channel effects are defined the dopings around S&D in the MOS device.

(v) Leakage currents are function of S&D and substrate doping.

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Resistance of Semiconductor bar with known doping



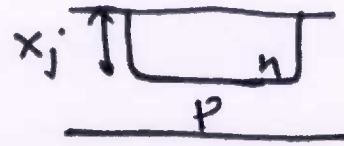
$$R = \frac{\rho L}{A} = \frac{\rho L}{w \cdot t} = \left(\frac{\rho}{t}\right) (L/w)$$

$\left(\frac{\rho}{t}\right)$ is called Sheet Resistivity or Sheet Resistance R_s

$\therefore R = R_s (L/w)$; (L/w) is seen as ASPECT RATIO

$$\sigma = \text{Conductivity} = \frac{1}{\rho}$$

$$= (q \mu_n n + q \mu_p p)$$



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If we apply a voltage V across the Bar,

the $E = \frac{V}{L}$ = Electric field along direction of current flow

The Current density $J = \sigma E$ (This is Drift Current)

(vi) In the Doped region, the sheet resistance is evaluated as

$$R_s = \frac{\rho}{x_j}$$

where x_j is Junction Depth.

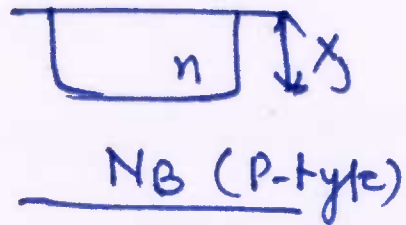
and $\rho = \frac{1}{(q \mu_n n + q \mu_p p)}$ is Specific Resistivity

If n is not uniform along x (direction of current flow)

———— N_0
 $\downarrow x$
 ——— $N(x)$

then we have $n(x)$ & $p(x)$ functions

For a junction, $n(x)$ is profile from surface to junction.



If N_B is Base or Background concentration, and doping of impurities are done from surface, ($N_{\text{surface}} = N_0$), then average σ is

$$\sigma = \frac{1}{x_j} \int_0^{x_j} q \{ n(x) - N_B \} \mu n(x) dx$$

$$\therefore R_s = \frac{\rho}{x_j} = \frac{1}{\sigma x_j} = \frac{1}{\int_0^{x_j} q [n(x) - N_B] \mu(x) dx}$$



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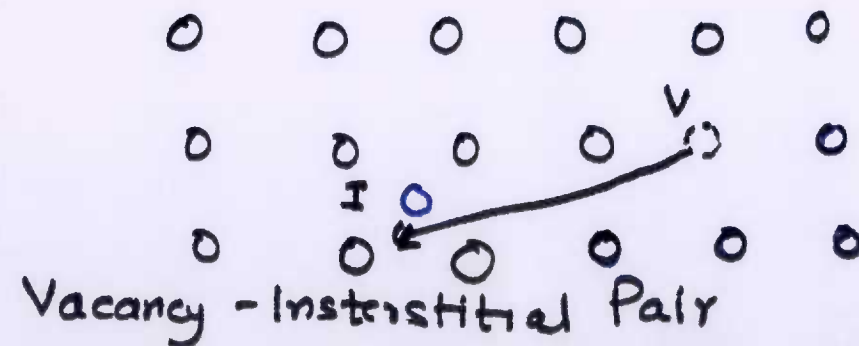
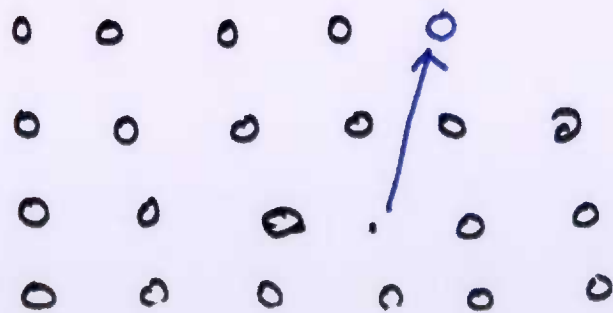
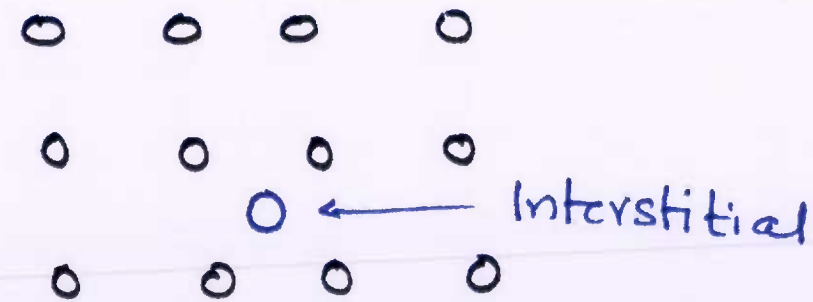


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Impurities can contribute to Resistivity, only if they occupy substitutional site in Silicon Crystal. Point Defects are very useful in impurity Incorporation. We recall these defects by figures shown below:

Vacancy (Schottky defect)



Point Defects density is a function of Substrate Concentration (N atom/cc), activation energy and Temperature.



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If n_s is no. of Defects/cc created in crystal of Concentration N atoms/cc

By Thermodynamic Principles, this defect density is due to availability of them in N atoms/cc at temp T . Mathematically no of ways it can happen is

$$C_{n_s}^N = \frac{N!}{n_s! (N - n_s)!}$$

Further Entropy S of this system can be written as

$$S = k \ln [C_{n_s}^N]$$

$$\therefore T.S = kT \ln \left[\frac{N!}{n_s! (N-n_s)!} \right]$$

$$L = !$$

The Binding energy of atoms (Enthalpy) is given by

$$H = E_s \cdot n_s$$



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where E_s is activation energy of the process

If Defects are to be Created, the Gibbs Free Energy G must first be evaluated and then optimised.

We have

$$G = n_s \cdot E_s - T.S \quad \left[(H - T.S) = G \right]$$

$$\text{or } G = n_s \cdot E_s - kT [\ln N! - \ln (N-n_s)! - \ln (n_s)!]$$

$$(G = H - TS)$$

$$\therefore G = n_s E_s - kT \left[N \ln(N) - N - (N - n_s) \ln(N - n_s) + (N - n_s) - n_s \ln n_s + n_s \right]$$

$$= n_s \cdot E_s - kT \left[N \ln N - (N - n_s) \ln(N - n_s) - n_s \ln n_s \right]$$

We know
 $\ln x! = x \ln x - x$

By Thermodynamic Principles,

maximum defects occurs when $\frac{dG}{dn_s} = 0$ (G minimum)

$$\therefore \frac{dG}{dn_s} = 0 = E_s - kT \left[0 - \frac{(N - n_s)}{(N - n_s)} (-1) + \ln(N - n_s) - \frac{n_s}{n_s} - \ln n_s \right]$$

$$0 = E_s - kT \left[\ln(N - n_s) - \ln n_s \right]$$



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$$\propto \frac{E_s}{kT} = \ln\left(\frac{N-n_s}{n_s}\right)$$

$$\propto e^{E_s/kT} = \frac{N-n_s}{n_s} = \frac{N}{n_s} - 1 \approx \frac{N}{n_s} \quad N \gg n_s$$

$$\therefore n_s = N e^{-E_s/kT}$$

Hence if we know activation energy of Vacancy or Interstitial formation, then we can find their density at a temperature T.

Clearly n_s increases with increase of Temperature

Since Crystal Growths are at v. high temperature, there is very large probabilities of Creation of Vacancy & Interstitial.



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In General n_s for interstitial = N_{I0} is different n_s for Vacancies = N_{V0}

In Equilibrium these conc. can be found to fit to a model which gives

$$N_{I0} = N_{Si} \cdot e^{-E_{SI0}/kT}$$

$$\& N_{V0} = N_{Si} \cdot e^{-E_{SV0}/kT}$$

given by

$$N_{I0} = 10^{27} \exp[-3.8 \text{ eV} / kT]$$

$$N_{V0} = 9 \times 10^{23} \exp[-2.6 \text{ eV} / kT]$$



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