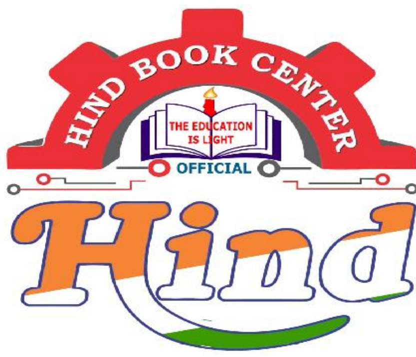

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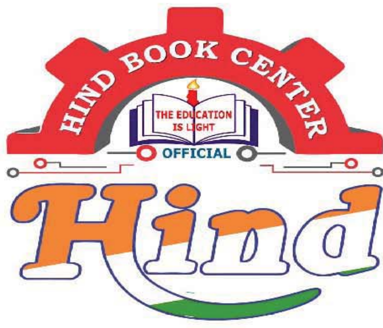

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IC FABRICATION

*NPTEL → Prof. Nandita Dasgupta. (VLSI Fabrication).

* SK Gandhi

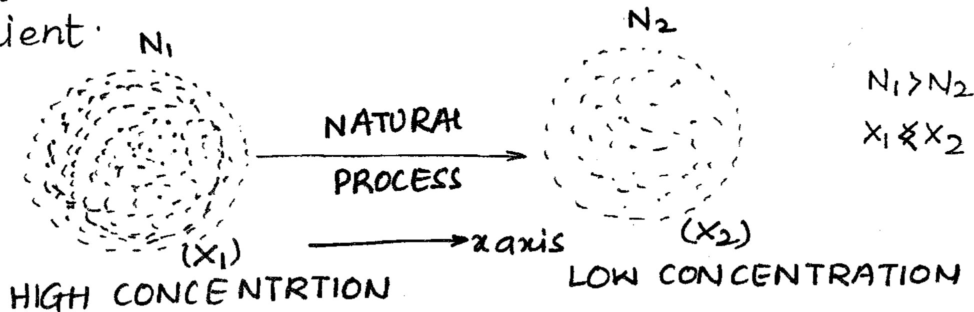
* oxidation, Ion Implantation diffusion → numericals.

* DOPING:

i) Diffusion.
ii) Ion Implantation.
iii) Epitaxy

i) DIFFUSION:

* Diffusion means movement of material under concentration gradient.



* As

$$J = -D\frac{dn}{dx}$$ ← FICKS 1st Law of Diffusion.

Hence -ve sign.

D = diffusion const.

J = Flux (always +ve). (we always say that flux is +ve).

$\frac{dn}{dx}$ = Concentration gradient

$$\frac{dN}{dx} = \frac{N_2 - N_1}{x_2 - x_1}$$ ← -ve quantity

* FICKS IInd LAW OF DIFFUSION:

* Ficks 2nd law of diffusion states that:

$$\nabla \cdot J = -\frac{\partial \rho_v}{\partial t}$$

$$\nabla = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z}$$

* For one dimension we get:

$$\frac{\partial J}{\partial x} = -\frac{\partial N}{\partial t}$$

$$J = -D\frac{\partial N}{\partial x} \quad \text{---- (i)}$$

$$\frac{\partial J}{\partial x} = -\frac{\partial N}{\partial t} \quad \text{---- (ii)}$$

diff. eqn (i) w.r.t x we get:-

$$\frac{\partial J}{\partial x} = -D\frac{\partial^2 N}{\partial x^2}$$

from eqn (ii) we get:-

$$-\frac{\partial N}{\partial t} = -D\frac{\partial^2 N}{\partial x^2}$$

$$\boxed{D\frac{\partial^2 N}{\partial x^2} = \frac{\partial N}{\partial t}} \leftarrow \text{wave Equation}$$

N: concentration.
x: space.
t: time

* N is a funcn of Both space and time.

$$\boxed{N = f(x, t)}$$

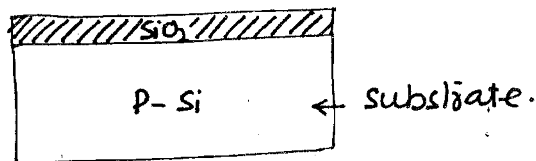
* TYPES OF DIFFUSION:-

i) Predeposition / Infinite source Diffusion.
ii) Drive in / limited source diffusion.

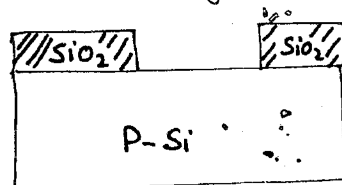
i) Predeposition / Infinite Source Diffusion:-

Diode Formation

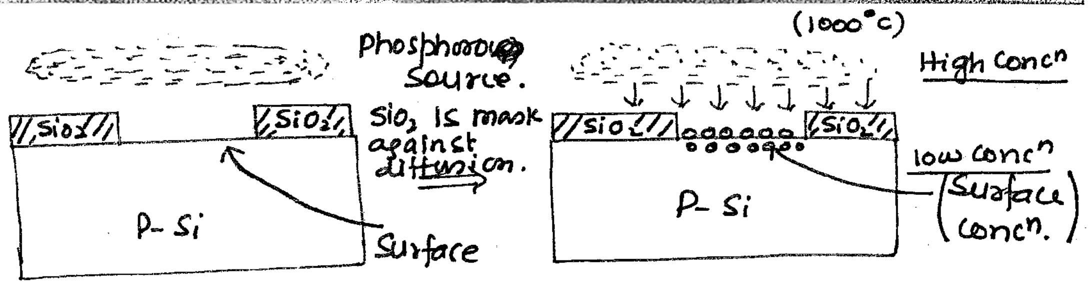
a) Take P substrate.



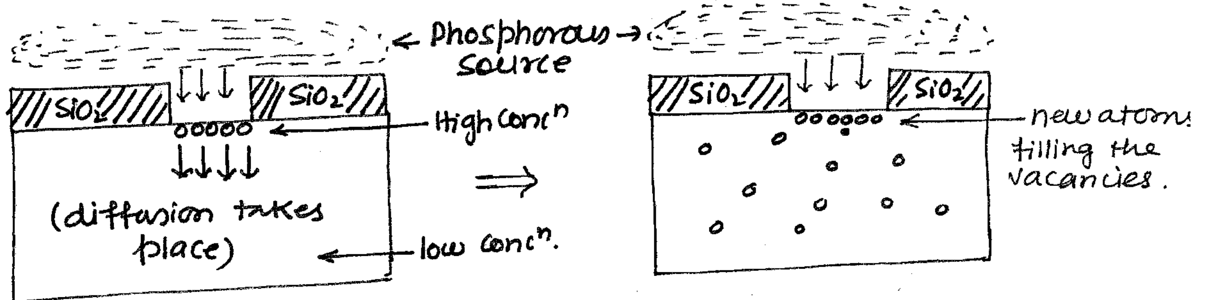
b) open a window using lithography + Etching



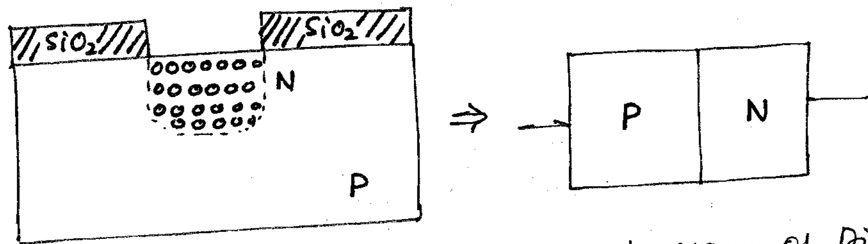
3)



(4)



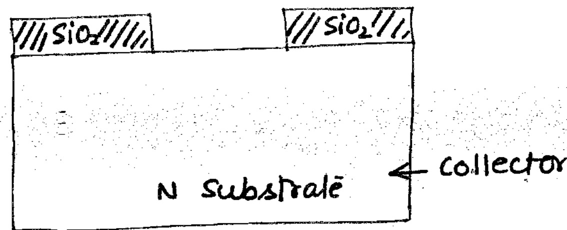
5) Finally,



* Diffusion occurs at 1000°c and to stop the process of Diffusion decrease the temperature.

* BJT FORMATION (NPN).

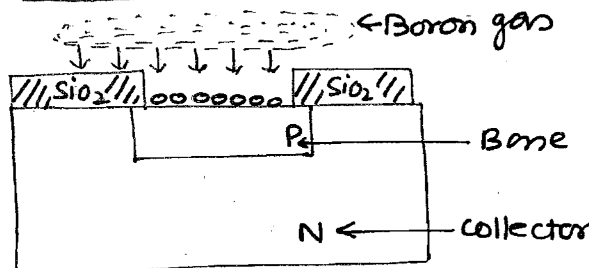
1) Take N substrate



Note: .

* Contacts are also to be connected.

2)



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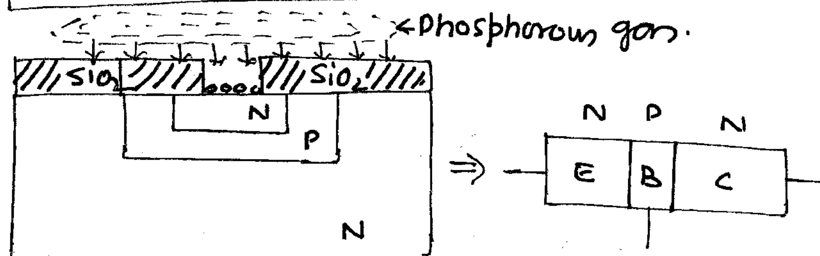
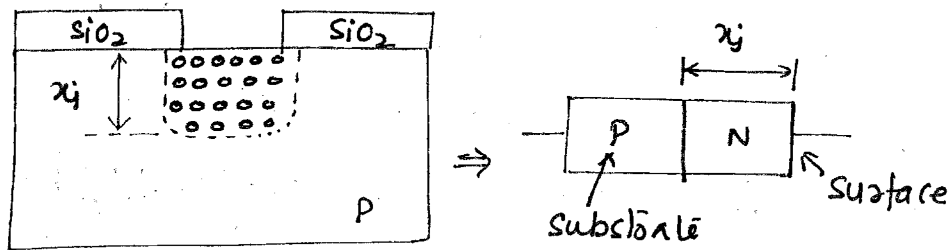
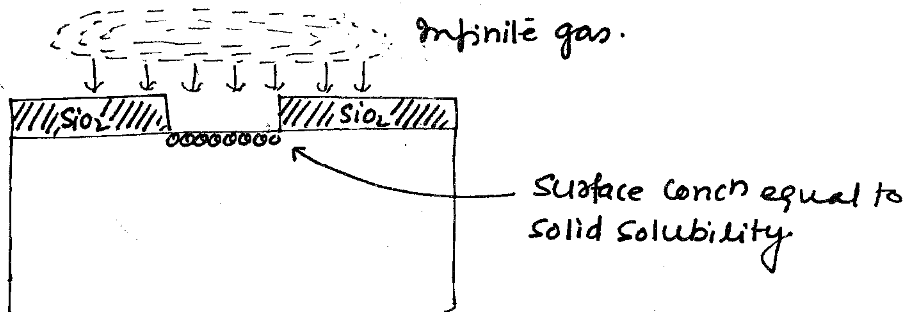


* **Parameters of Diffusion:** → Junction Depth. → Doping Profile. → Surface concentration.

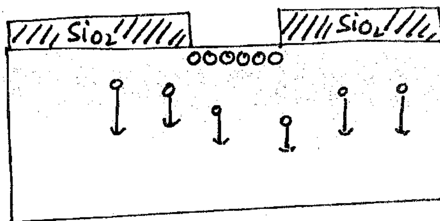


x_j: Junction Depth ie distance from surface where junction forms.

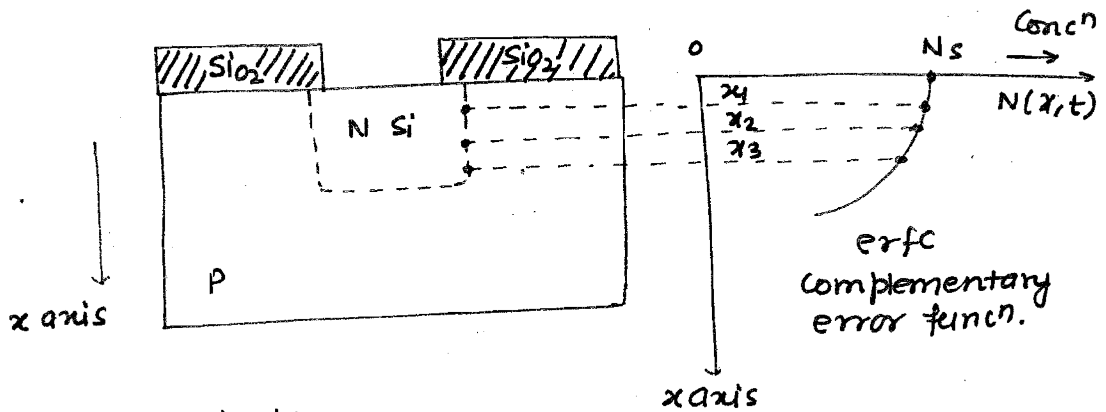
* **Surface concn in Predeposition:**



* Solubility is a funcn of Temp.
* surface concn is always constant ie the vacancies created at surface remain const.



* DOPING PROFILE:



We know that:

$$D\frac{\partial^2 N}{\partial x^2} = \frac{\partial N}{\partial t}$$ ← Partial differential equation.

$$N(x,t)\Big|_{x=\infty} = 0$$

$$N(x,t)\Big|_{x=0} = N_s$$ ← surface conc^n.

$$N(x,t)\Big|_{t=0} = 0.$$ ← Boundary conditions

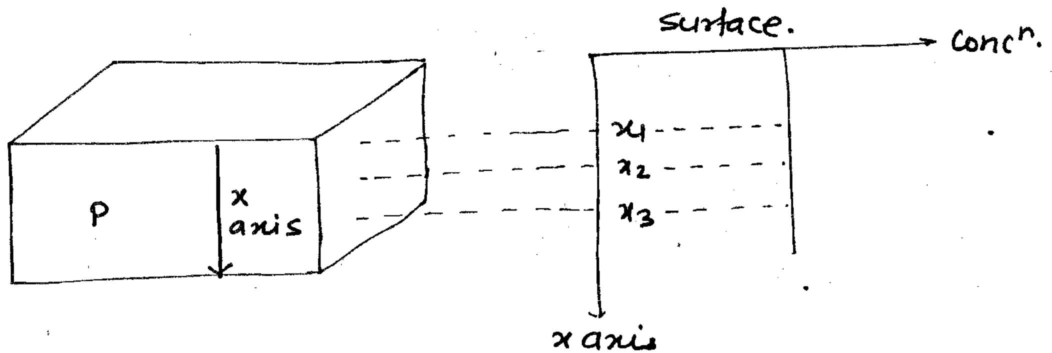
* Solution for the Partial differential equation is given as:

$$N(x,t) = N_s \text{erfc}(x/2\sqrt{Dt}).$$

t: time.

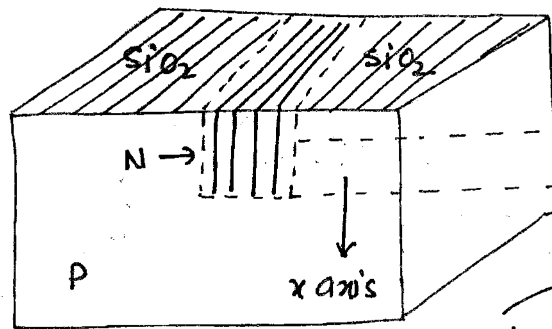
* <u>EPITAXY</u> is <u>method of UNIFORM DOPING</u>:

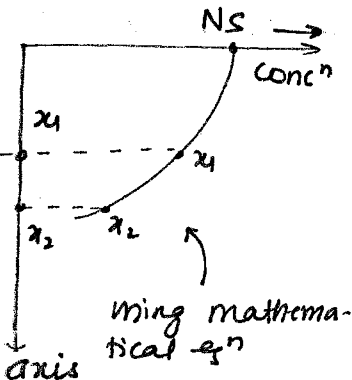
<u>Note</u>:



~~UNIF~~ <u>UNIFORMLY DOPED SUBSTRATE</u>.

* at constant temp.
* N_s is constant at given temp.

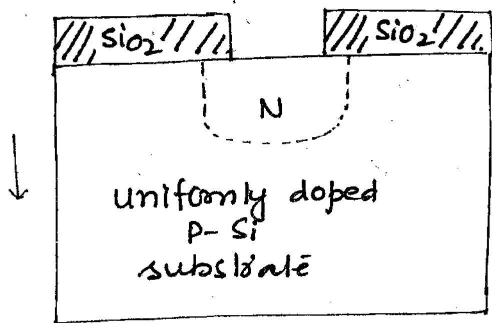


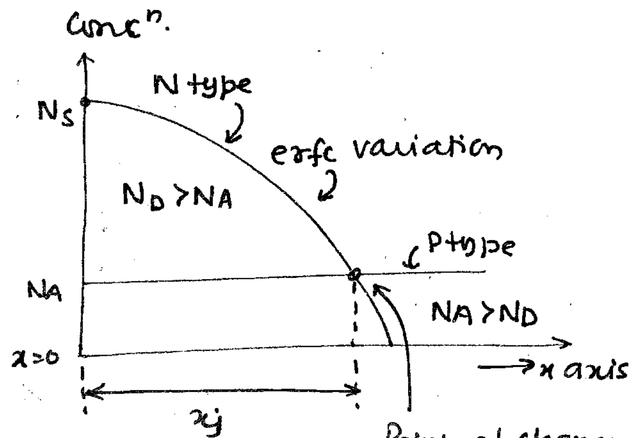


(profile of N type material) (Predeposition case)

*Junction Depth:

* Consider a uniformly doped p type substrate.
* Assume N type diffusion has been done





N_A: Acceptor concn
N_D: Donor concn.

* Juncn forms when material changes from N type to P type and vice versa.
* At the juncn ie $\boxed{x = x_j}$ ← Point of Intersection of curves.

$$\boxed{N_A = N(x, t)}$$

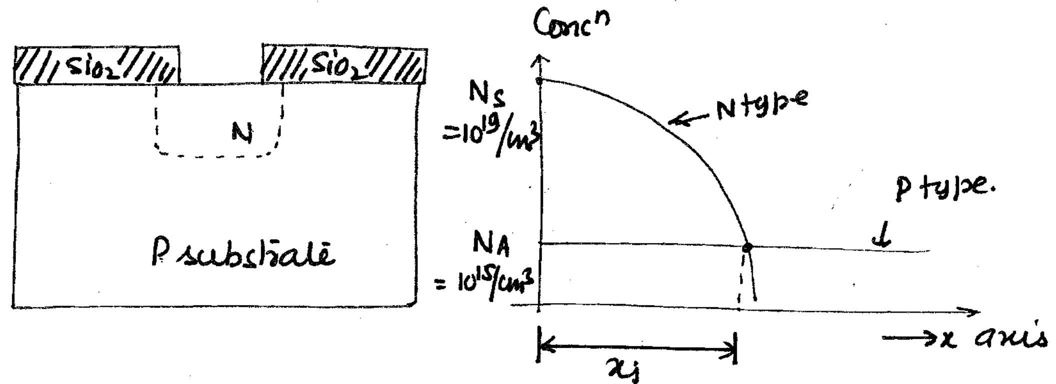
so, $$\boxed{N_A = N_s \operatorname{erfc}\left(x/2\sqrt{Dt}\right) = N(x, t).}$$

Q1) Phosphorous is diffused into uniformly doped P type substrate with background concn of $10^{15}/cm^3$ at T=1100°c. The diffusion constant at this temp is 10^{-12} cm²/sec ; solid solubility of phosphorous and silicon is $10^{19}/cm^3$ at 1100°c. Assume predeposition time of 1 hour. Find the Junc^n Depth?

erfc of 2.75 = 10^{-4}

$$erfc(2.75) = 10^{-4}.$$

Soln:



* At the junction:

$$N_A = N(x,t) = N_s \, erfc\left(x_j / 2\sqrt{Dt}\right)$$

$$10^{15} = 10^{19} \, erfc\left(x_j / 2\sqrt{Dt}\right)$$

$$10^{-4} = erfc\left(x_j / 2\sqrt{Dt}\right).$$

So, $$2.75 = \frac{x_j}{2\sqrt{Dt}}$$

or $$x_j = 2.75 \times 2 \times \sqrt{10^{-12}\, cm^2/sec \times 3600\, sec}$$

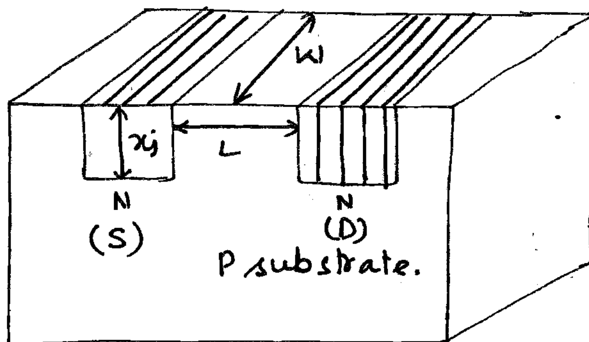
$$\boxed{x_j = 3.3\,\mu m}$$

Note:

L: channel length.

W: channel width

x_j: Junc^n depth.



(N MOS)

Note:

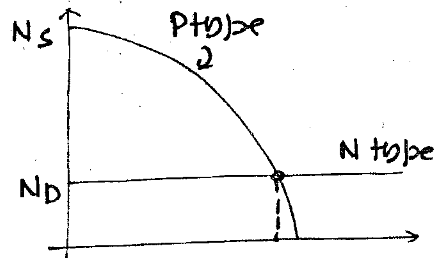
* Junc^n depth is decided during Diffusion process

* W/L Ratio decided during Lithography process. (lithography)

* x_j is important parameter in MOSFET fabrication.

Q2) Boron is diffused into an n type sc with back ground concn of $10^{14}/cm^3$. The predeposition is carried out for 2 hrs. Assume diffusion const of 5×10^{-13}. Solid solubility of $10^{20}/cm^3$. Find the juncn depth.

$\text{erfc}(3.45) = 10^{-6}$.



Soln:

$$N_s \, \text{erfc}(x_j/2\sqrt{Dt}) = N_D$$

$$10^{14} = 10^{20} \, \text{erfc}(x_j/2\sqrt{Dt})$$

$$10^{-6} = \text{erfc}(x_j/2\sqrt{Dt})$$

So, $$\boxed{\frac{x_j}{2\sqrt{Dt}} = 3.45}$$ *** ← in Prelims.

$$x_j = 2\times3.45\times\sqrt{5\times10^{-13}\times2\times3600}$$

$$x_j = 60\times10^{-6}\times2\times3.45$$

$$\boxed{x_j = 414\times10^{-6}\text{ cm} = 4.14\,\mu m}$$

Note (Prelims):

$\text{erfc}(3.45) = 10^{-6} \Rightarrow \text{erfc}^{-1}(10^{-6}) = 3.45$
$\text{erfc}(2.75) = 10^{-4} \Rightarrow \text{erfc}^{-1}(10^{-4}) = 2.75$
} Constant Value.

Now,

$$N_A = N_s \, \text{erfc}(x_j/2\sqrt{Dt})$$

$$\left(\frac{N_A}{N_s}\right) = \text{erfc}(x_j/2\sqrt{Dt})$$

$$\text{erfc}^{-1}(N_A/N_s) = \text{constant} = \frac{x_j}{2\sqrt{Dt}} = K.$$

So, $$x_j = 2\sqrt{Dt}\times K.$$

$$\boxed{x_j \propto \sqrt{t}}$$