Integrated ckt

circuit: connection of Active and passive elements
Active Elements: BJT, MOSFET, JFET, etc
Passive Elements: R, L, C, etc.

Integrated circuit: connection of Active and Passive components on the top of the substrate. (Semiconductor or Insulator)

Integrated ckt	Discrete ckt
(1) small size	(1) More size
(2) small power consumption	(2) large power consumption.
(3) low cost (∵ IC fabrication is a batch process)	(3) High cost
(4) More durable	(4) less durable

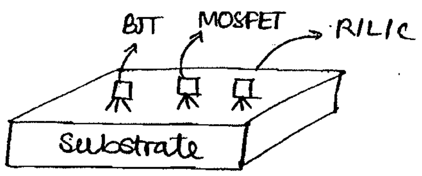
Disadvantage:

IC's cannot be repaired but can only be replace.

Classification of ICs

- Monolithic IC's
  - Thin/Thick film IC's
  - Hybrid IC's
- On the basis of level of integration
  - (1) SSI
  - (2) MSI
  - (3) LSI
  - (4) VLSI
  - (5) ULSI
- Analog/Digital IC's
- Bipolar ICs
  - CMOS ICs
  - BiCMOS ICs

Monolithic Ic's



Mono → Single
lithos → Stone

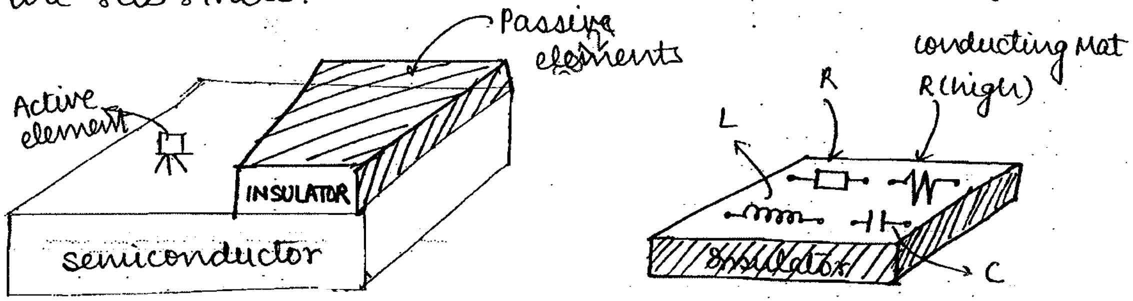
→ All the Active and Passive elements are fomed on the top of the single S.C substrate.

> Disadvantage: Heavy value of R-L-C is restricted in Monolithic IC's because heavy value of R,L,C occupy more area of substrate.

Thin and Thick Film Technology

> By appearance, both Thick & Thin film ICs are very similar.

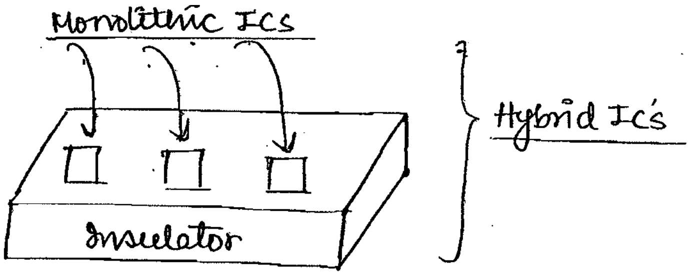
> Active elements are fabricated on the top of the S.C substrate & passive elements are fabricated on the top of the insulating portion of the substrate.



Advantage: Heavy value of R,L and C we can get compared to Monolithic.

Thin Film	Thick Film
(1) conducting film is deposited by using sputtering process (or) vapour deposition	(1) conducting film is deposited by using screen printing (or) silk screen printing

Hybrid ICs



Level of Integration

No of transistors / unit area

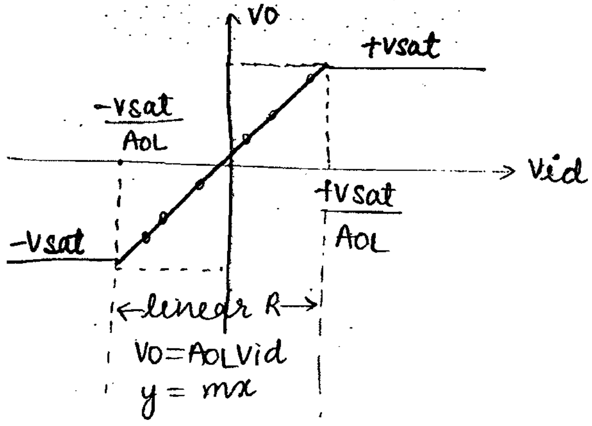
(1) Small Scale integration (SSI) : 1-10 $\xrightarrow{\text{Packing Density}}$ $P<1$
(2) Medium " " (MSI) : $10-10^2$ $\xrightarrow{\text{''}}$ $1<P<2$
(3) Large " " (LSI) : 10^2-10^4 $\xrightarrow{\text{''}}$ $2<P<4$
(4) Very Large " " (VLSI) : 10^4-10^6 $\xrightarrow{\text{''}}$ $4<P<6$
(5) Ultra Large " " (ULSI) : $>10^6$ $\xrightarrow{\text{''}}$ $P>6$

* Packing Density (P)

$\boxed{P = \log_{10}(Q)}$ Q: No of Tx in per unit Area

Analog And Digital ICs

Analog IC (Linear IC's)	Digital IC (Non-Linear IC's)
I/P → Analog	I/P → Digital
O/P → Analog	O/P → Digital
eg: OpAmp IC (IC-741) IC-555 timer	eg: FlipFlop



# **Bipolar ICs**	**CMOS ICs**
(1) low packing density	(1) Higher packing density bcoz MOSFET occupies less Area compared to BJT.
(2) More Power consumption	(2) less Power consumption
(3) BW = high	(3) BW = low
(4) Gain = high	(4) gain = low
(5) speed = high	(5) speed = low

Gain

BJT: $g_m = \frac{\partial I_C}{\partial V_{BE}} = \frac{I_C}{\eta V_T} = \frac{I_S e^{V_{BE}/\eta V_T}}{\eta V_T}$

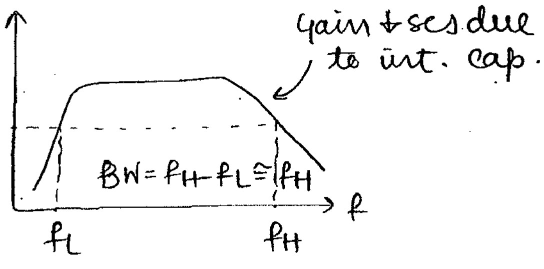
$V_{BE}\uparrow$, $I_C\uparrow$ exponentially $\longrightarrow$ $g_m\uparrow$ exponentially

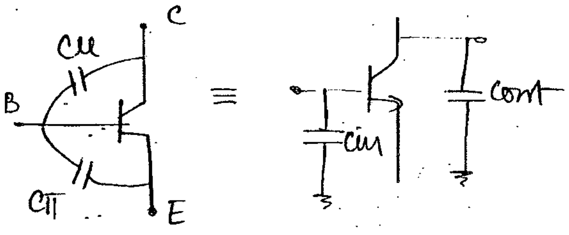
MOSFET: $g_m = \frac{\partial I_D}{\partial V_{GS}} = \sqrt{2 I_D \mu C_{ox}\left(\frac{W}{L}\right)}$

$I_D \propto (V_{GS}-V_T)^2$ $\quad V_{GS}\uparrow \longrightarrow I_D\uparrow$ with square of $V_{GS} \Rightarrow g_m\uparrow$

$\boxed{g_m(BJT) > g_m(MOSFET)}$ $\quad \therefore$ gain (BJT) > gain (MOSFET)

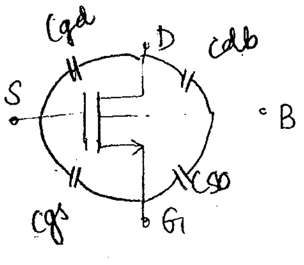
BW

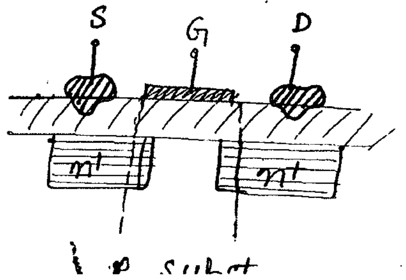




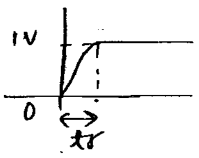
$f_H = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)}$

BW = $f_H - f_L \simeq f_H$.





Speed Rise Time $(t_r) = \frac{0.35}{f_H}$



$\therefore \boxed{t_r\,BJT < t_r\,MOSFET}$

↓

Speed of operation is high in BJT.

Note: • When speed, BW and Gain are important then we'll prefer Bipolar technology.

- If low power consumption & area are main concerns then we'll prefer CMOS technology.

• **BiCMOS** [Bipolar + CMOS].

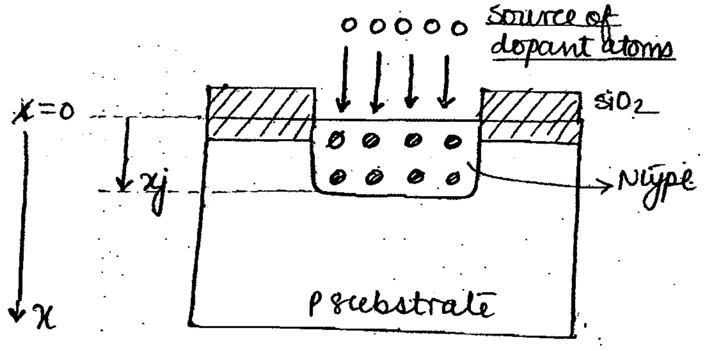
→ Some portion of the complete ckt is designed using Bipolar technology. and some portion is designed using CMOS tech depending on requirements for a particular circuit.

Doping process

(1) Diffusion process of doping

(2) Ion implantation

(3) Epitaxy.



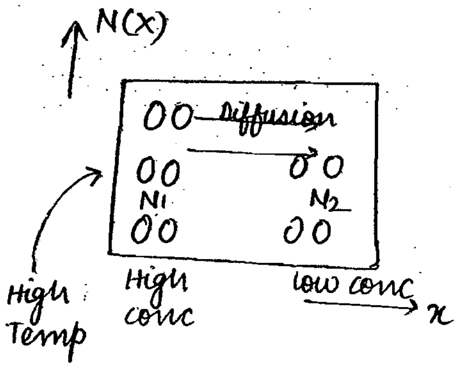
$x_j \rightarrow$ junction depth

(1) Diffusion Process of Doping

$\frac{dN}{dX} \neq 0$

$N(X) \Rightarrow$ conc of dopant atoms $\left[\frac{atoms}{cm^3}\right]$

$\frac{dN}{dX} \rightarrow$ change in conc of atoms
or
conc. gradient



Fick's First law of Diffusion

$$\boxed{J = -D\frac{dN}{dx}}$$

D → Diffusivity of atoms $\left(\frac{cm^2}{sec}\right)$

J → atomic flux ≡ No of dopant atoms crossing unit cross sectional in per unit time.

Fick's second law of Diffusion

$$\boxed{\nabla . J = \frac{-dN}{dt}}$$

one dimension → $\frac{dJ}{dx} = \frac{-dN}{dt}$

$$\frac{d}{dx}\left[-D\frac{dN}{dx}\right] = \frac{-dN}{dt} \Rightarrow \boxed{D\frac{\partial^2 N}{\partial x^2} = \frac{\partial N}{\partial t}}$$

(or)

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

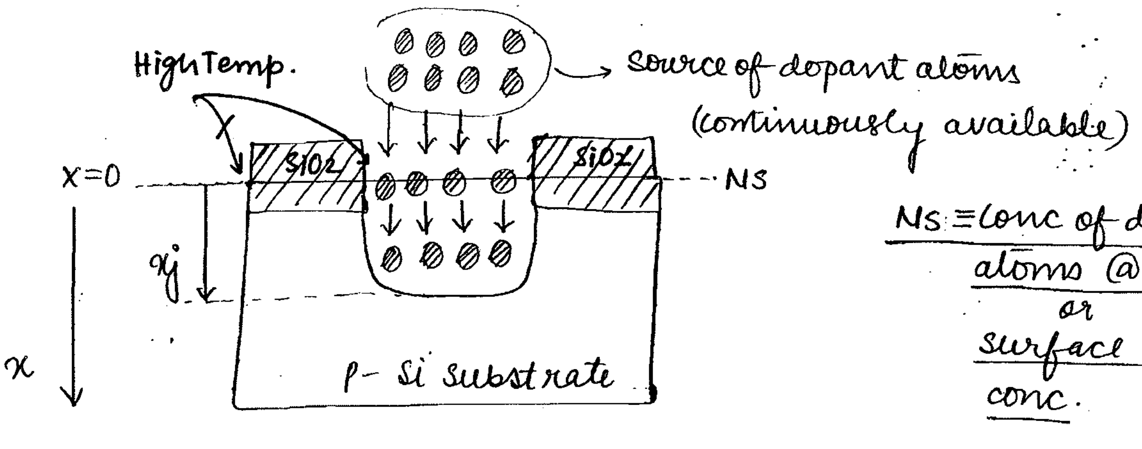
$$\Rightarrow \boxed{\frac{\partial N}{\partial t} = D\frac{\partial^2 N}{\partial x^2}}$$: Diffusion Equation

- Diffusion process of doping will take place in two steps:–

(1) Pre-deposition (infinite source diffusion)

(2) Drive-in (finite / limited source diffusion)

(1) Pre-Deposition (infinite source diffusion)



Ns ≡ Conc of dopant atoms @ x=0
or
surface atoms conc.

*Solid solubility limit : Extent upto which we can dissolve a solid

$N_S = N_0 \longrightarrow$ constant

it is limited by solid solubility test

$$\frac{\partial N}{\partial t} = D\frac{\partial^2 N}{\partial x^2} \longrightarrow N(x,t) = ?$$

Apply:

<u>boundary condition</u>

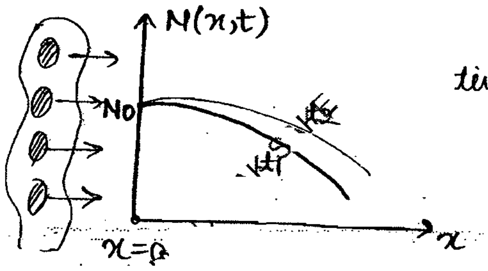
(1) $N(0,t) = N_0$

(2) $N(\infty,t) = 0 \rightarrow$ very deep doping/jn is not possible by diffusion process of doping.

(3) $N(x,0) = 0$

$$\boxed{N(x,t) = N_0 \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)} \; cm^{-3} \quad *$$

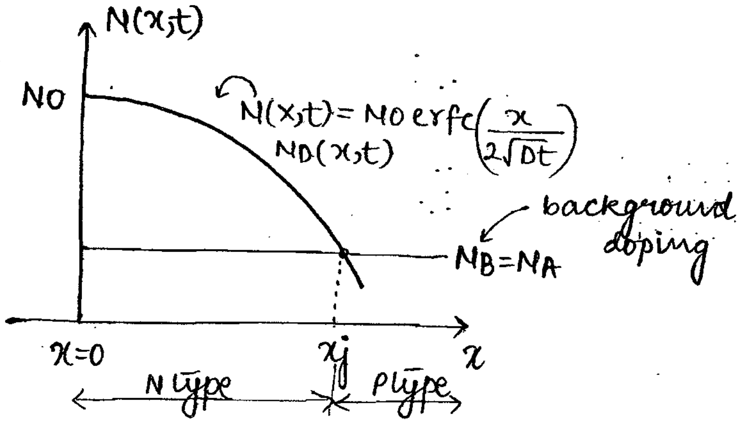
~~complementary error fn profile~~.



time : $t_2 > t_1$

<u>fig: complementary error fn profile</u>

Suppose, <u>P-sub is uniformly doped</u>,



@ $x = x_j$,

$N(x,t) = N_B$

$$N_0 \operatorname{erfc}\left(\frac{x_j}{2\sqrt{Dt}}\right) = N_B$$

- Doping parameters
  - → surface dopant conc ✓
  - → x_j depth ✓
  - → Doping profile ✓
  - → Doping Dose *

Imp

Doping Dose: Total No of ~~atoms~~ Dopant atoms/cm² (Q)

$$Q = \int_0^\infty N(x,t)\,dx \quad \text{atoms/cm}^2$$

$$Q = \int_0^\infty N_0\,\mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)dx = N_0\int_0^\infty \mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)dx$$

let $\frac{x}{2\sqrt{Dt}} = v$

$dx = 2\sqrt{Dt}\,dv$

$x=0$, $x=\infty$

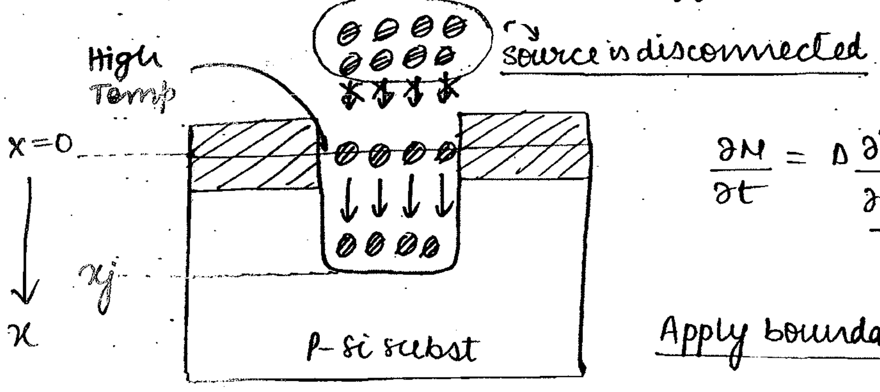
$v=0$, $v=\infty$

$$Q = N_0\int_0^\infty \mathrm{erfc}(v)\,2\sqrt{Dt}\,dv$$

$$Q = 2N_0\sqrt{Dt}\underbrace{\int_0^\infty \mathrm{erfc}(v)\,dv}_{\frac{1}{\sqrt{\pi}}}$$

$$* \boxed{Q = 2N_0\sqrt{\frac{Dt}{\pi}}} \ \frac{\text{atoms}}{\text{cm}^2}$$

(2) Drive-in (finite source diffusion)



$$\frac{\partial N}{\partial t} = D\frac{\partial^2 N}{\partial x^2} \longrightarrow N(x,t) = ?$$

Apply boundary cond,

(1) $N(\infty,t) = 0$ deep doping not possible

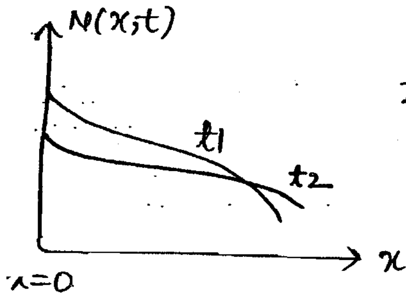
(2) $Q = \int_0^\infty N(x,t)\,dx$ = constant

$$\boxed{N(x,t) = \frac{Q}{\sqrt{\pi Dt}}\,e^{-x^2/4Dt}}^{*} \quad \text{atoms/cm}^3$$

Gaussian profile

$$\boxed{N_S = N(0,t) = \frac{Q}{\sqrt{\pi D t}}}$$

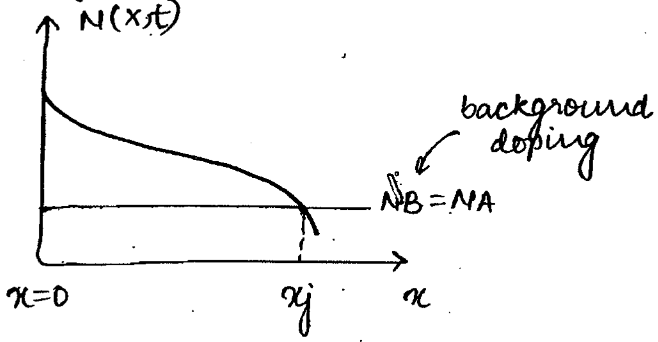
$t\uparrow$, $N_S\downarrow$



time

$t_2 > t_1$

Suppose, substrate is uniformly doped P type



@ $x = x_j$,

$N(x,t) = N_B$

$$\frac{Q}{\sqrt{\pi D t}}\, e^{-x_j^2/4Dt} = N_B$$

$x_j = ?$

Note: • $\mathrm{erfc}(x) = 1 - \underbrace{\mathrm{erf}(x)}_{\text{error fn}}$

• $$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-y^2}\,dy$$

Note: Practically we carry ~~out~~ predeposition for certain duration of time & then we carry out drive in.

Predeposition	Drive in
(1) Doping profile is complementary error fn. $\boxed{N(x,t) = N_0\, \mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)}$	(1) Doping profile is Gaussian type. $\boxed{N(x,t) = \frac{Q}{\sqrt{\pi D t}}\, e^{-x^2/4Dt}}$
(2) New atoms are diffusing inside substrate	(2) No new atoms are coming only surface atoms are diffusing inside substrate.
(3) ~~New atoms are diffusing inside substrate~~ This step is responsible	(3) ~~No~~ The purpose of drive in is to change the jn depth.

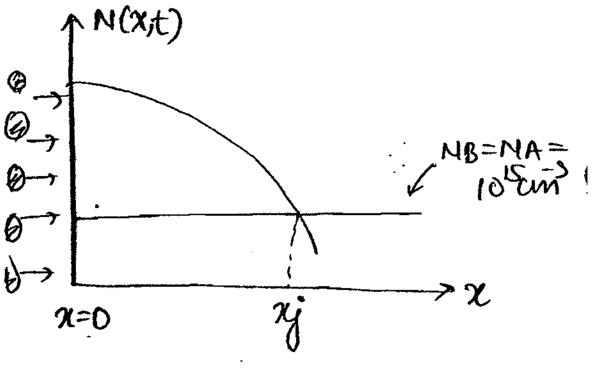
Q Phosphorous is diffused into uniformly doped P type subst with background doping conc of $10^{15}/cm^3$ @ T = 1100°c. The diff const of atoms @ this temp is $D = 10^{-12} cm^2/s$. solid solubility of P in si is $10^{19}/cm^3$ @ 1100°c. Assume pre-dep time of 1hr. Find the jn depth. Given $erfc(2.75) = 10^{-4}$.

Sol: $N_B = N_A = 10^{15} cm^{-3}$

$N_0 = 10^{19} cm^{-3}$

$D = 10^{-12} cm^2/s$

$t = 1 hr = 60 \times 60 \ sec$



Predep → $N(x,t) = N_0 \cdot erfc\left(\frac{x}{2\sqrt{Dt}}\right)$.

@ $x = x_j \Rightarrow N(x,t) = N_B$

$N_0 \, erfc\left(\frac{x_j}{2\sqrt{Dt}}\right) = N_B$

$erfc\left(\frac{x_j}{2\sqrt{Dt}}\right) = \frac{N_B}{N_0} \rightarrow \left(\frac{x_j}{2\sqrt{Dt}}\right) = erfc^{-1}\left(\frac{N_B}{N_0}\right) \Rightarrow erfc^{-1}\left(\frac{10^{15}}{10^{19}}\right) = erfc^{-1}(10^{-4})$

$x_j = 2\sqrt{Dt}\, erfc^{-1}(10^{-4}) = 2\sqrt{Dt}\ erfc\ (10^{-4})$

$x_j = 2\sqrt{10^{-12} \times 60 \times 60}\ (2.75) \underset{\text{(default)}}{cm} \rightarrow 2 \times 10^{-6} \times 60 \times 2.75\ cm \xrightarrow[\text{convert }(\mu m)]{} = \underline{3.3 \mu m}$ //

Q B is diffused into N type S.C with background doping conc of $10^{14}/cm^3$. The pre deposition is carried out for 2 hrs. Assume deffusion const of atoms $D = 5 \times 10^{-13} cm^2/s$. solid solubility of B in si is $10^{20}/cm^3$. Find the jn depth. Given $erfc(3.45) = 10^{-6}$

Sol: $N_B = N_D = 10^{14} cm^{-3}$

$t = 2 hrs = 2 \times 60 \times 60$

$D = 5 \times 10^{-13} cm^2/s$

$N_0 = 10^{20} cm^{-3}$

Predep: $N(x,t) = N_0 erfc\left(\frac{x}{2\sqrt{Dt}}\right)$

@ $x = x_j \rightarrow N(x,t) = N_B$

$N_0 \, erfc\left(\frac{x}{2\sqrt{Dt}}\right) = N_B$

$erfc\left(\frac{x}{2\sqrt{Dt}}\right) = \frac{N_B}{N_0}$

$\frac{x_j}{2\sqrt{Dt}} = erfc^{-1}\left(\frac{N_B}{N_0}\right) = erfc^{-1}\left(\frac{10^{14}}{10^{20}}\right)$

$erfc^{-1}(10^{-6}) = 3.45$

$x_j = 2\sqrt{5 \times 10^{-13} \times 2 \times 60 \times 60} \times 3.45$

$= 2 \times 10^{-6} \times 60 \times 3.45\ cm$

$\underline{x_j} = \underline{4.14 \mu m}$ //

Q For a certain dopant in P type Si subst, if pre dep is carried out for 1hr then jn depth is observed to be 3μm. If pre dep is carried out for 2 hrs then jn depth is __?

Sol: $t_1 = 1\text{hr} \longrightarrow x_{j1} = 3\mu m$

$t_2 = 2\text{hr} \longrightarrow x_{j2} = ?$

@ $x = x_j$ $\quad N(x,t) = N_B$

$$N_0 \,\text{erfc}\left(\frac{x_j}{2\sqrt{Dt}}\right) = N_B$$

$$\text{erfc}\,\frac{x_j}{2\sqrt{Dt}} = \left(\frac{N_B}{N_0}\right) \rightarrow x_j = 2\sqrt{Dt}\,\overbrace{\left(\text{erfc}^{-1}\left(\frac{N_B}{N_0}\right)\right)}^{\text{const}} \longrightarrow x_j \propto \sqrt{t}$$

$$\frac{x_{j1}}{x_{j2}} = \sqrt{\frac{t_1}{t_2}} \longrightarrow \frac{3\mu m}{x_{j2}} = \sqrt{\frac{1}{2}} \longrightarrow x_{j2} = \sqrt{2} \times 3\mu m$$ //

Q P is diffused into uniformly doped P type substrate with background doping of $10^{17}/cm^3$. Assume pre-dep time of 2 hrs & diff const of 10^{-12} cm^2/sec. solid solubility of P in subst is $10^{21}/cm^3$ @ diff Temp 1050°C. Given ~~erfc(of~~ $\underline{\text{erfc}(2.75) = 10^{-4}}$. Find :

(i) Dose

(ii) jn depth.

Sol: $N_B = N_A = 10^{17}$

$t = 2\text{hrs} = 2 \times 60 \times 60$

$D = 10^{-12}\ cm^2/sec$

$N_0 = 10^{21}\ cm^{-3}$

(i) **Dose**

$$Q = 2N_0\sqrt{\frac{Dt}{\pi}}$$

$$Q = 2 \times 10^{21} \times \sqrt{\frac{10^{-12} \times 2 \times 60 \times 60}{\pi}}$$

$$Q = \frac{2 \times 10^{21} \times 60 \times \sqrt{2} \times 10^{-6}}{\pi}$$

$$= \frac{120 \times \sqrt{2} \times 10^{15}}{\pi}$$

(ii) $x_j = 2\sqrt{Dt}\ \text{erfc}^{-1}\left(\frac{N_B}{N_0}\right)$

$$= 2\sqrt{10^{-12} \times 2 \times 60 \times 60}\ \text{erfc}^{-1}\left(\frac{10^{17}}{10^{21}}\right)$$

$$= 2 \times 10^{-6} \times 60 \times \sqrt{2} \times \underline{2.75}$$

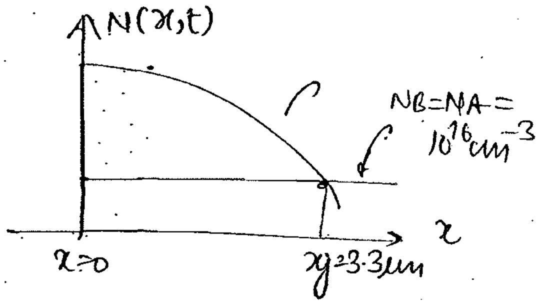
$$= 4.667\mu m$$ //

Q P is diffused into P type Si with original doping conc of substrate being $10^{-16}\,cm^{-3}$ @ 1150°C. Given that solid solubility of P in Si @ 1150°C is $10^{20}\,cm^{-3}$ and the diffusion coeff @ this temp is $10^{-12}\,cm^2/sec$ calculate:

(i) total no of P atoms / unit area of Si surface after pre dep time of 1hr

(ii) jn depth after pre-deposition.

(iii) After pre dep, drive in is carried out for 2 hrs @ same temp. what will be the final jn depth & surface atoms conc? given $erfc(2.75) = 10^{-4}$, $erfc(3.45) = 10^{-6}$.



Sol: $N_B = N_A = 10^{16}\,cm^{-3}$ @ 1150°C

$N_0 = 10^{20}\,cm^{-3}$ "

$D = 10^{-12}\,cm^2/sec$ "

(i) $t = 1hr = 60 \times 60$ sec

$$Q = 2N_0\sqrt{\frac{Dt}{\pi}} = 2 \times 10^{20} \times \sqrt{\frac{10^{-12} \times 60 \times 60}{\pi}} = 2 \times 10^{20} \times 10^{-6} \times 60 \times \sqrt{\frac{1}{\pi}}$$

$$= 120 \times 10^{14} \times \sqrt{\frac{1}{\pi}}\ \frac{atoms}{cm^2}$$

$$= 6.77 \times 10^{15}\ atoms/cm^2$$

ii) $x_j = 2\sqrt{Dt}\ erfc^{-1}\left(\frac{N_B}{N_0}\right)$

$$x_j = 2\sqrt{10^{-12} \times 60 \times 60}\ erfc^{-1}\left(\frac{10^{16}}{10^{20}}\right) = 2 \times 10^{-6} \times 60\ erfc^{-1}(10^{-4})$$

$$= 120 \times 10^{-6} \times \cancel{10}\, 2.75 = 3.3\,\mu m.$$

iii) $t = 2hr = 2 \times 60 \times 60$ sec @ 1150°C

$$N(x,t) = \frac{Q}{\sqrt{\pi Dt}}\, e^{-x^2/4Dt} = N_s e^{-x^2/4Dt}$$

$$N_s = N(0,t) = \frac{Q}{\sqrt{\pi Dt}} = \frac{6.77 \times 10^{15}}{\sqrt{\pi \times 10^{-12} \times 2 \times 60 \times 60}}\ \frac{atoms}{cm^3} = 4.5 \times 10^{19}\ \frac{atoms}{cm^3}$$

@ $x = x_j \rightarrow N(x,t) = N_B$

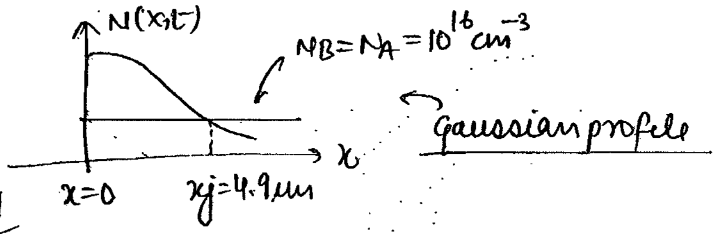
$$N_s\, e^{-x_j^2/4Dt} = N_B$$

$$\therefore e^{-x_j^2/4Dt} = \frac{N_B}{N_s}$$

$$x_j^2 = 4Dt \ln\left(\frac{N_s}{N_B}\right)$$

$$= 4 \times 10^{-12} \times 2 \times 60 \times 60 \times \ln\left(\frac{4.5 \times 10^{19}}{10^{16}}\right)$$

$$\boxed{x_j = 4.92\,\mu m}$$



HW

Q P is diffused into Si for an infinite source @ 1000°C for 30 mins

(i) Find the total amt of P atoms/unit area that has gone into Si & also calculate the jn depth.

(ii) After step(i) source is shut off & sample is subjected to drive in @ 1200°C. If the final conc of dopant @ surface is to be maintained $5\times10^{19}/cm^3$. What should be the duration of drive in?

(iii) If the original substrate doping was $10^{15}/cm^3$ what is jn depth after drive in?

Given: $D(@1000°C) = 3\times10^{-14}\ cm^2/sec$

$D(@1200°C) = 2.5\times10^{-12}\ \frac{cm^2}{sec}$

solid solubility of P @ 1000°C is $10^{21}/cm^3$ and $erfc(3.45) = 10^{-6}$.

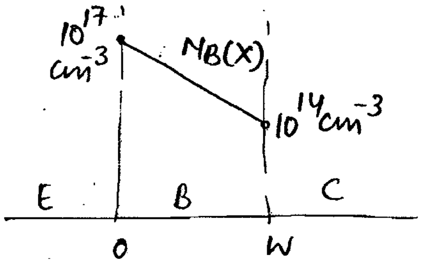
Q The base of an NPN BJT T1 has a linear doping profile $N_B(x)$ as shown below. The base of another npn BJT T_2 has a uniform doping N_B of $10^{17}/cm^3$. All other para are identical for both devices. Assuming that hole density profile is the same as that of doping, the CE current gain of T_2 is:

(a) Approx 0.3 times that of T1

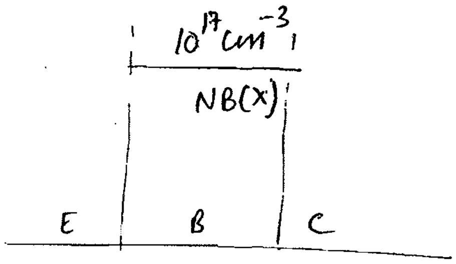
(b) Approx 0.5 times that of T1

(c) " 2.5 " "

(d) " 2.0 " "



sol: T_2:



CE current gain, $\beta \propto \frac{1}{\text{doping of base}}$ or $\beta \propto \frac{1}{\text{doping dose in base}}$

$$\frac{\beta_1}{\beta_2} = \frac{\text{doping dose in base of T2}}{\text{doping dose in base of T1}}$$

doping dose in T2 : $\int_0^W N_B\,dx = \int_0^W 10^{17}\,dx = 10^{17}W$

doping dose in T1 : $N_B(x) = \left(\frac{10^{17}-10^{14}}{0-W}\right)x + 10^{17}$

$$N_B(x) \cong \frac{10^{17}x}{-W} + 10^{17}$$

$$\int_0^W N_B(x)\,dx = \int_0^W \left(\frac{10^{17}x}{-W}+10^{17}\right)dx \rightarrow 10^{17}(x)_0^W - \frac{10^{17}}{W}\left(\frac{x^2}{2}\right)_0^W$$

$$\Rightarrow 10^{17}W - \frac{10^{17}}{W}\left(\frac{W^2}{2}\right) \Rightarrow 10^{17}W - \frac{10^{17}}{2}W = \frac{10^{17}}{2}W$$

$$\frac{\beta_1}{\beta_2} = \frac{10^{17}W}{\frac{10^{17}W}{2}} = 2 \Rightarrow \boxed{\beta_2 = \frac{1}{2}\beta_1 = 0.5\beta_1}$$ //

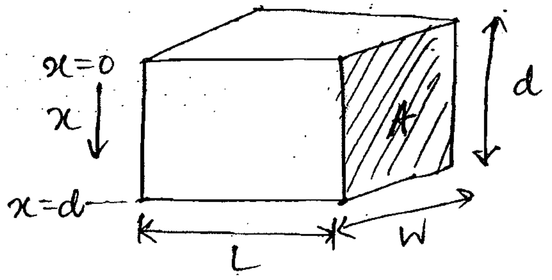
Q consider an N type s.c as shown in fig where doping varies with depth 'd' linearly as $x=0$; $N_D = 10^{14}\,cm^{-3}$
$x=d$; $N_D = 10^{16}\,cm^{-3}$

Assume mobility indpt of doping & $\mu_n = 3800\,\frac{cm^2}{V\text{-sec}}$
given $W = L = 5\mu m$ & 'd' = $5\mu m$. Find Resistance of bar ___ Ω.

Sol: $\sigma = nq\mu_n + \cancel{pq\mu_p}$ neglect

$\sigma = nq\mu_n = N_D q\mu_n$

$\therefore \sigma(x) = N_D(x)\,q\mu_n$



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

$$= \frac{l}{N_D(x)\,q\mu_n A}$$

$$= \frac{l}{N_D(x)\,q\mu_n\,(d\times W)} = \frac{l}{q\mu_n W\,N_D(x)\,d}$$

$$R = \frac{L}{q\mu_n W \int_0^d N_D(x)\,dx} \xrightarrow[\text{doped } N_D(x)=N_D]{\text{uniformly}} R = \frac{L}{q\mu_n W N_D d}$$

$$\int_0^d N_D(x)\,dx = \int_0^d \left(\frac{10^{16}}{d}x + 10^{14}\right) dx$$

$$= \frac{10^{16}}{d}\left(\frac{x^2}{2}\right)_0^d + 10^{14}(x)_0^d \longrightarrow \frac{10^{16}}{d}\left(\frac{d^2}{2}\right) + 10^{14}d$$

$$= \frac{10^{16}}{2}d + 10^{14}d = d\left(\frac{10^{16}}{2} + 10^{14}\right)$$

$$R = \frac{\cancel{L}}{q\cancel{W}\cancel{\mu_n}\,d\left(\frac{10^{16}}{2}+10^{14}\right)} = \frac{1}{1.6\times10^{-19}\times3800\times5\times10^{-4}\left[\frac{10^{16}}{2}+10^{14}\right]}\,\Omega$$

$$\boxed{R = 644.99\,\Omega}$$

Diffusion of Impurities inside silicon

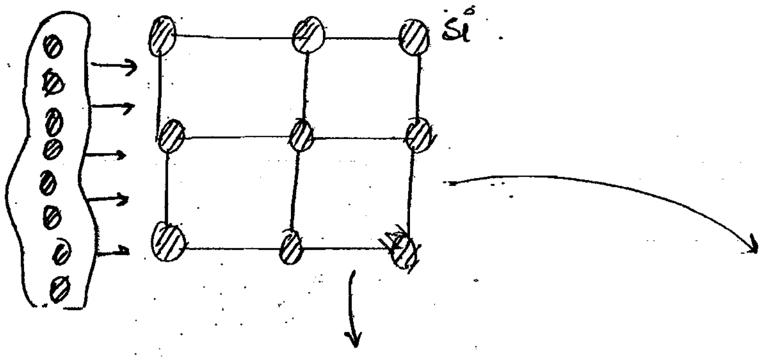
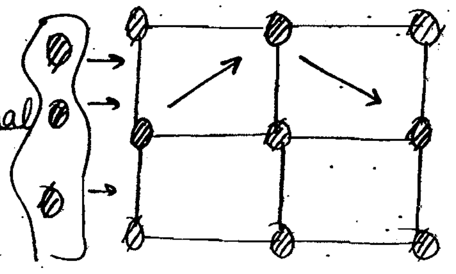


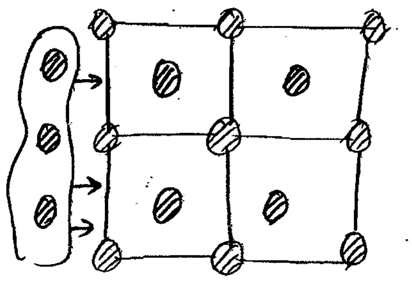
fig: Interstitial type of impurities

(1) fig: substitutional type of impurity



eg: P, As, B, Al, etc
[5th grp, 3rd grp]

(2)



eg: lithium,
[1st grp]

N can
also.
size

Diffusion const & Temp Relation

$$\boxed{D = D_0 e^{-E_A/KT}}$$

EA → Activation energy (energy required to activate diffusion process)

k → Boltzmann const ≡ 8.625×10^{-5} eV/k

T → T (in K)

Do → const. indpt of temp.

$E_A = 3eV - 4eV$ for substitutional type impurity in Si

$E_A = 0.6eV - 1eV$ for interstitial type impurity in Si

(1) For substitutional type

$E_A = 3eV$ (let)

(i) @T=300K : $D = D_0 e^{-E_A/KT} = D_0 e^{-3/0.026} \Rightarrow D = D_0 \times 7.74 \times 10^{-51}$

$$\boxed{D \cong 0}$$

(ii) @T=1200K

$$kT = \frac{T}{11{,}600} = \frac{1200}{11600} = 0.103eV$$

$$D = D_0 e^{-3eV/0.103eV} = D_0 \times 2.62 \times 10^{-13}$$

$$\boxed{D \rightarrow \text{sufficient}}$$

Diffusion of impurities will take place

(2) For interstitial type of

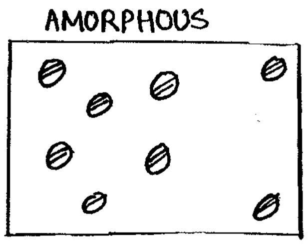
$E_A = 0.6eV$ (let)

(i) T=300K : $D = D_0 e^{-0.6/0.026} \Rightarrow D_0 \times 9.50 \times 10^{-11}$

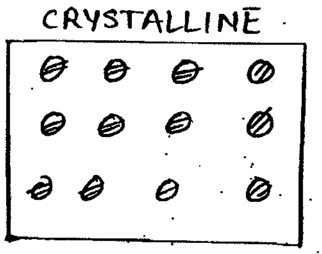
Diffusion of impurities will take place @ T=300K

Note: Diffusion of interstitial impurities take place @ low temp whereas diffusion of substitutional type impurity will take @ high T.

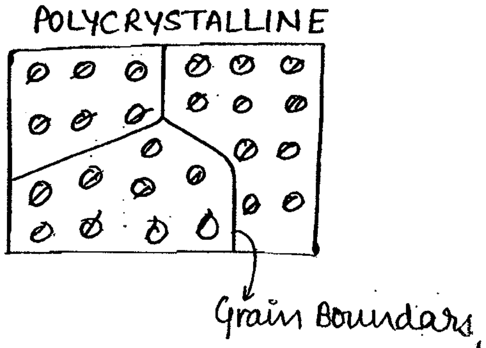
(II) Ion Implantation



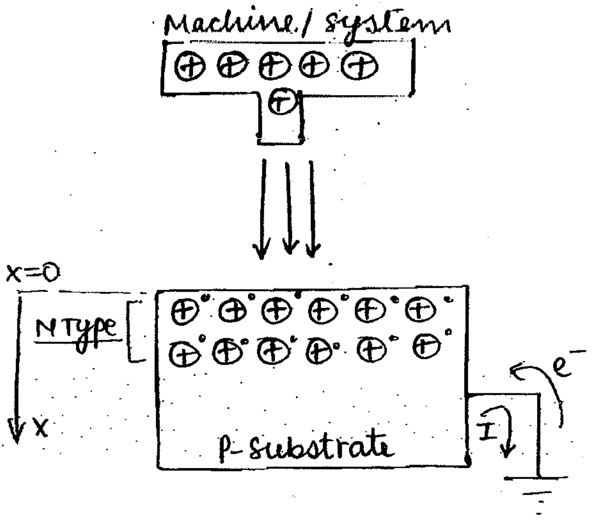
→ Random Arrangement of the atoms

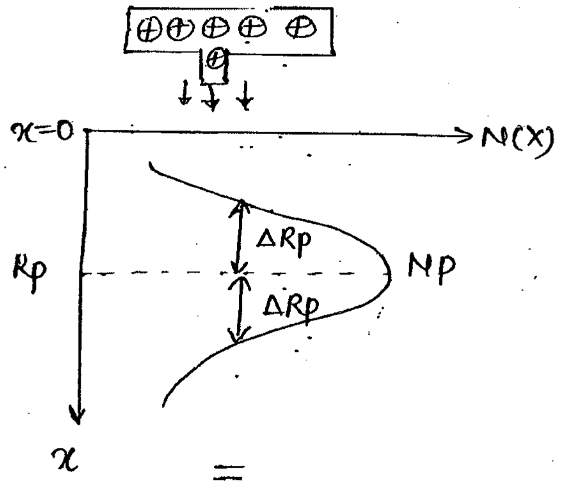


→ systematic/periodic arrangement of atoms



(1) Ion Implantation through morphous si





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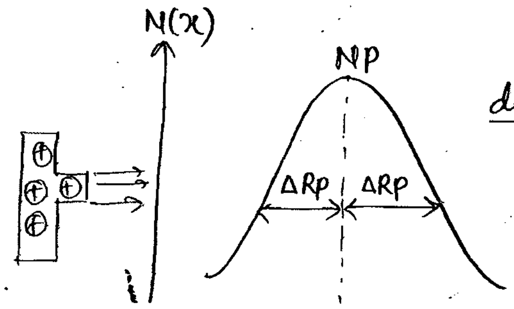


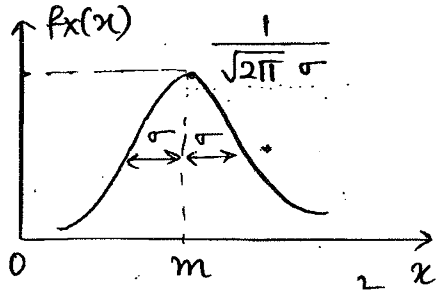
doping profile

Np: Peak conc of ions

Rp: Projected Range(or) projected dist ⇒ Avg dist travelled by ions before

$$\boxed{N(x) = N_p\, e^{-(x-R_p)^2/2\Delta R_p^2}}\ \text{cm}^{-3}$$

Extra Discussion on Gaussian fn



$$f_x(x) = \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-(x-m)^2/2\sigma^2}$$

σ : stddev / straggle

σ^2 = variance

$$\int_{-\infty}^{\infty} f_x(x)\,dx = 1$$

$$\int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-(x-m)^2/2\sigma^2}\,dx = 1$$

$$\frac{1}{\sqrt{2\pi}\,\sigma}\int_{-\infty}^{\infty} e^{-(x-m)^2/2\sigma^2}\,dx = 1$$

$$\boxed{\int_{-\infty}^{\infty} e^{-(x-m)^2/2\sigma^2}\,dx = \sqrt{2\pi}\,\sigma} \ *$$

Doping dose (Q):

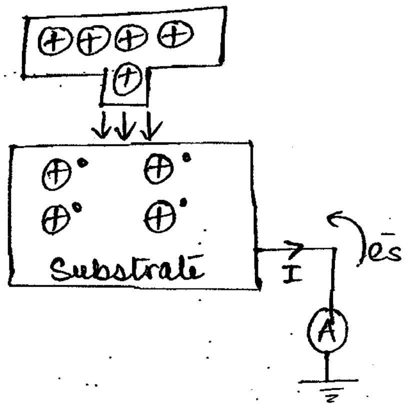
$$Q = \int_{-\infty}^{\infty} N(x)\,dx$$

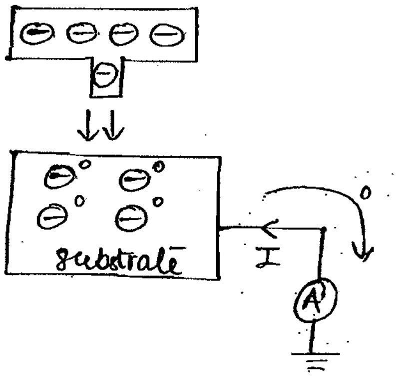
$$Q = \int_{-\infty}^{\infty} N_p\, e^{-(x-R_p)^2/2\Delta R_p^2}\,dx$$

$$Q = N_p \int_{-\infty}^{\infty} e^{-(x-R_p)^2/2\Delta R_p^2}\,dx = N_p \cdot \sqrt{2\pi}\,\Delta R_p \ \text{atoms}$$

$$\boxed{\begin{aligned} Q &= N_p\sqrt{2\pi}\,\Delta R_p \\ N_p &= \frac{Q}{\sqrt{2\pi}\,\Delta R_p} \end{aligned}}\ *$$

- **Ion's current / current Density**





$$I = \frac{nq}{t} \longrightarrow n = \frac{It}{q}$$

No of ions = No of atoms = No of e^- supplied by Gnd (or) taken by GND.

$$\text{Dose}(Q) = \frac{\text{No of ions}}{cm^2} = \frac{\text{No of dopant atom}}{cm^2}$$

$$Q = \frac{n}{A} = \frac{It}{Aq}$$

$$\boxed{Q = \frac{Jt}{q}}\ *$$

Ion's stopping

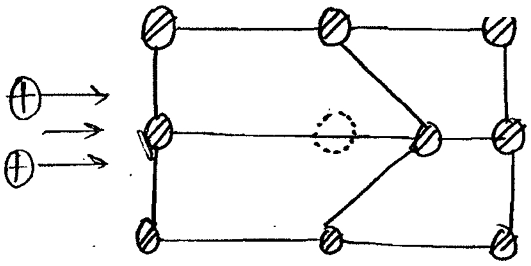
(1) Nucleus stopping

(2) electronic stopping

(1) **Nucleus stopping**

⇒ The energetic ions collide with nucleus of the si atom and transfer its energy to si atom and finally comes to Halt.

⇒ In this stopping si atom gets displaced from its position hence, defects are created but these defects are recovered by '**thermal Annealing**' process



(2) **Electronic stopping**

⇒ The energetic ions collide with $\bar{e}$'s present in the si and after transferring its energy, ions come to the halt. In this stopping, ehps are generated.

* **Annealing Process:** In Annealing process, substrate is heated up @ high T & suddenly cool down

(i) **Furnace Annealing:** In furnace annealing, substrate is heated @ approx 1000K for 20 to 30 mins and then it cools down

disadv: (i) high thermal budget

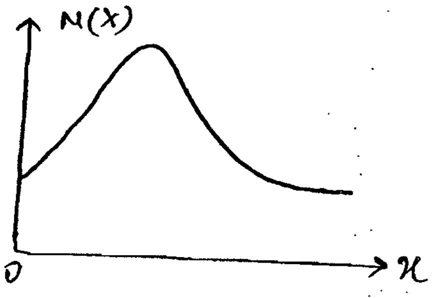
(ii) @1000K Temp diffusion of impurity also takes place hence, doping parameters will get disturbed.

(ii) **Rapid Thermal Annealing (RTA):** In RTA, substrate is heated up @ 600-800K Temp for 30 sec to 2 mins & then it cools down.

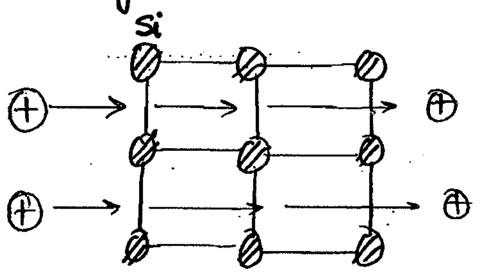
Adv: (i) low thermal budget

(2) Ion implantation through crystalline silicon

→ In crystalline si, ions may travel a longer distance before stop. Hence the doping profile is not symmetrical gaussian profile and actual profile will have some tail



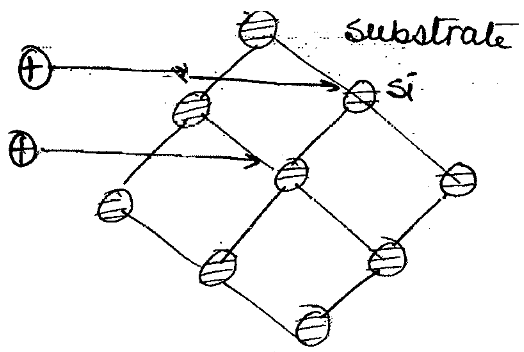
* **Ion's channeling:**



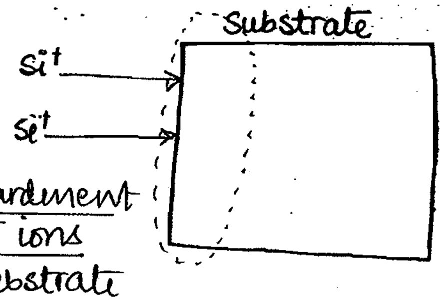
→ In a crystalline si, ions may travel a longer distance without collision and may penetrate complete substrate. This is known as ions channeling.

→ To prevent ion's channeling;

(1) Tilt the substrate @ an angle ~~of~~ 7° to 10° before implantation.
✓



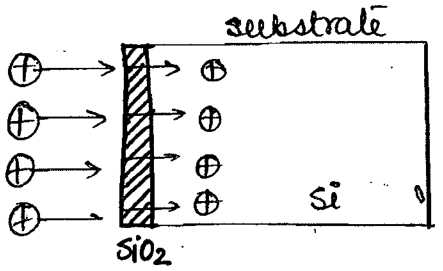
(2) Pre-Amorphization of substrate surface:
x



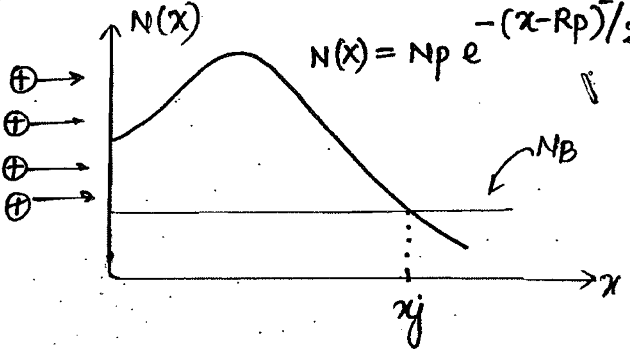
Bombardment of si^+ ions on substrate surface to amorphize it.

- Before ion implantation, upper surface of the subst is subjected to bombardment of si ions to get subst. surface Amorphous.
- And after this step, we can carry out ion implantation w/o Ion channeling.
- Annealing process can be

3) Ion implation through thin $\boxed{SiO_2 \text{ layer}}$.



*** Junction Depth :**



$$N(x) = N_p e^{-(x-R_p)^2/2\Delta R_p^2}$$

@ $x = x_j$:

$N(x) = N_B$

$N_p e^{-(x_j-R_p)^2/2\Delta R_p^2} = N_B$

$\boxed{x_j = ?}$

Q Phosphorous is implanted into p type Si sample with uniform doping conc of 10^{16} atoms/cm^3. If the beam current density is $2\mu A/cm^2$ & implantation is carried out for 10 mins. calculate

(i) Implanted dose — Given: $R_p = 1.1\mu m$

(ii) Peak impurity conc — $\Delta R_p = 0.3\mu m$

(iii) jn depth.

Sol: $N_B = N_A = 10^{16}$ atoms/cm^3

$J = 2\mu A/cm^2$

$t = 10$ mins

(i) $Q = ?$

(ii) $N_p = ?$

(iii) $x_j = ?$

(i) $Q = \frac{Jt}{q}$, $Q = N_p \sqrt{2\pi}\, \Delta R_p$.

$$Q = \frac{2\times10^{-6}\times(10\times60)}{1.6\times10^{-19}} \frac{\text{atoms}}{cm^2} \text{ (or) } \frac{\text{ions}}{cm^2}$$

$$Q = 7.5\times10^{15} \frac{\text{atoms}}{cm^2} \text{ (or) } \frac{\text{ions}}{cm^2}$$

(ii) $$N_p = \frac{Q}{\sqrt{2\pi}\,\Delta R_p} = \frac{7.5\times10^{15}}{\sqrt{2\pi}\times(0.3\times10^{-4})}$$

$$= 9.97\times10^{19} \frac{\text{ions}}{cm^3} \text{ or } \frac{\text{atoms}}{cm^3}$$

(iii) $N(x) = N_B$ @ $x = x_j$

$$N_p e^{-(x_j - R_p)^2/2\Delta R_p^2} = N_B$$

$$\frac{-(x_j - R_p)^2}{2\Delta R_p^2} = \ln\left(\frac{N_B}{N_p}\right)$$

$$-(x_j - R_p)^2 = 2\Delta R_p^2 \ln\left(\frac{N_B}{N_p}\right)$$

$$(x_j - R_p)^2 = 2\Delta R_p^2 \ln\left(\frac{N_p}{N_B}\right)$$

$$x_j - R_p = \pm\Delta R_p\sqrt{2\ln\left(\frac{N_p}{N_B}\right)}$$

$$x_j = R_p \pm \Delta R_p\sqrt{2\ln\left(\frac{N_p}{N_B}\right)}$$

$$x_j = (1.1\mu m) \pm (0.3\mu m)\sqrt{2\ln\left(\frac{9.97\times10^{19}}{10^{16}}\right)}$$

$$\boxed{x_j = 2.38\mu m} //$$

Q B is implanted @ 100 keV in n type Si with background doping conc of $10^{15}/cm^3$. If beam current is 1 mA and target area is $100 cm^2$.

(i) How long should be implantation ~~be~~ we carried out to realise a (i) dose of $4\times10^{15}/cm^2$.

(ii) calculate the location of PN jn & peak conc

given, $R_p = 3\mu m/MeV$

$\Delta R_p = 0.3 R_p$.

[100 keV]

Sol: $N_B = N_D = 10^{15} cm^3$

~~Ibeam 1mA~~ Ibeam = 1mA

$A = 100 cm^2$

$Q = 4\times10^{15}$

(i) $Q = \frac{Jt}{q} = \frac{I}{A}\cdot\frac{t}{q}$

$t = \frac{Qq\cdot A}{I} =$

$t = \frac{4\times10^{15}\times1.6\times10^{-19}\times100}{1\times10^{-3}}$ sec

$t = 64$ sec //

(ii) $x_j, N_p = ?$

$$N_p = \frac{Q}{\sqrt{2\pi}\,\Delta R_p} = \frac{4\times10^{15}}{\sqrt{2\pi}\times0.3\times0.3\times10^{-4}}$$

$$\boxed{N_p = 1.773\times10^{20}} //$$

$R_p = 3\mu m/MeV$

$R_p = 0.3\mu m$ for 0.1 MeV of ions energy

$\Delta R_p = 0.3R_p = 0.3\times0.3\mu m$

$N(x) = N(B)$ @ $x = x_j$

(iii) $x_j = R_p \pm \Delta R_p\sqrt{2\ln\left(\frac{N_p}{N_B}\right)}$

$x_j = 0.742\mu m$ //