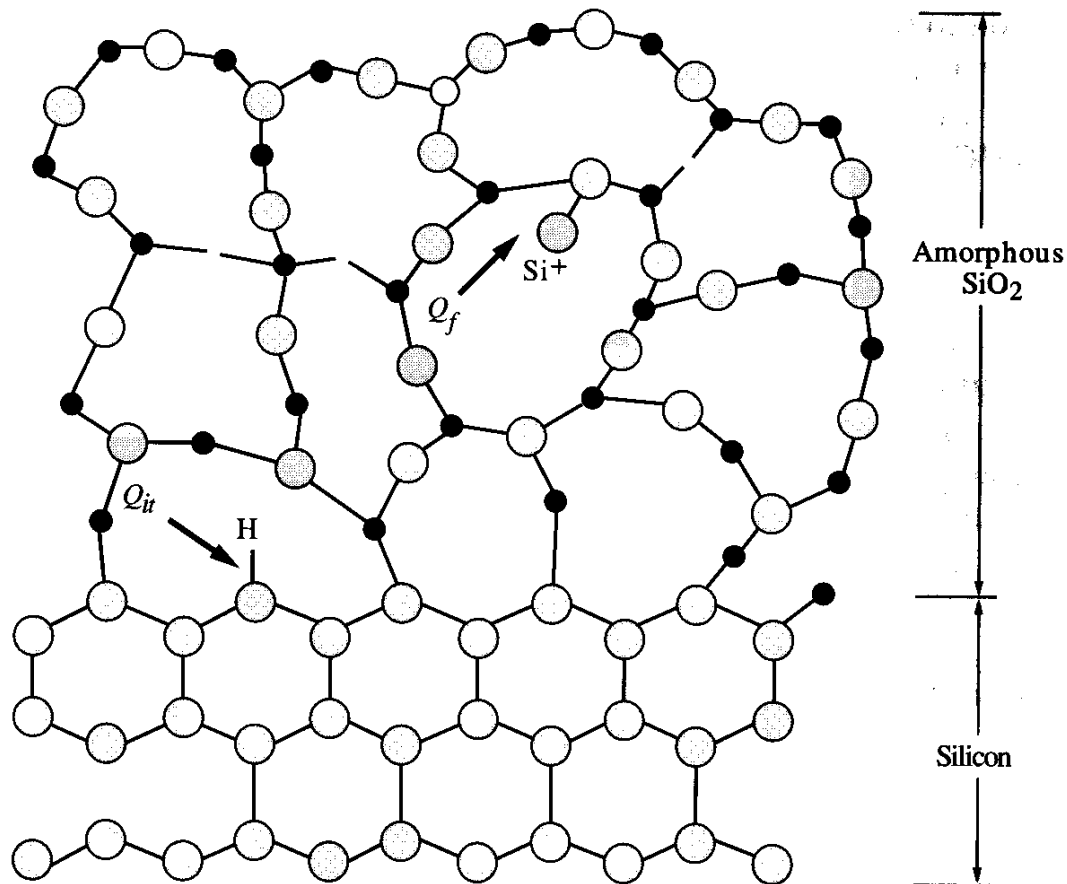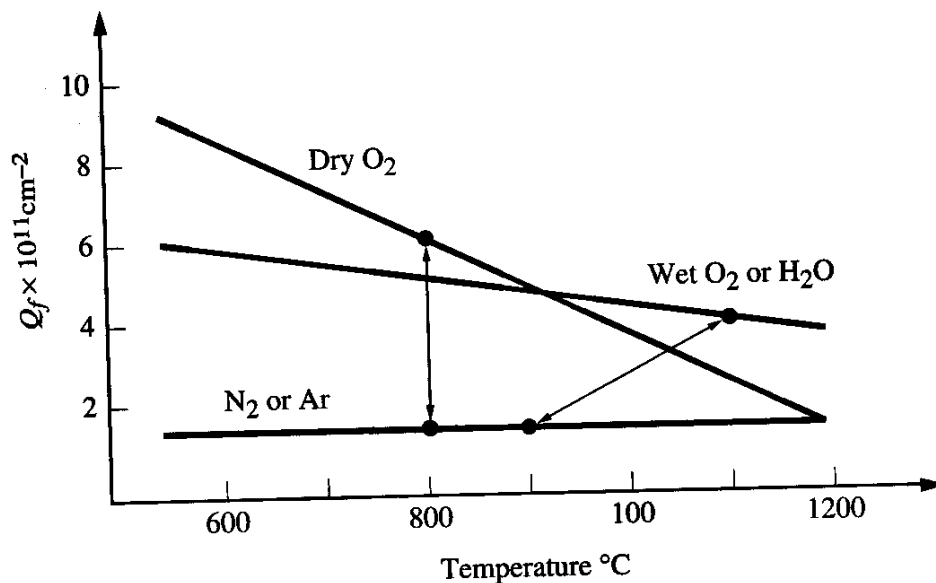# 6.5.13 Si/SiO$_2$ Interface charges

- **The bulk of the oxide consists mainly of rings of SiO4 tetrahedra, each with six Si atoms in the ring**
- **=Si• corresponding to Q$_f$ are located physically further away from the interface and thus are unable to trap carriers**
  The energy levels corresponding to Q$_f$ are located outside the bandgap

Dry O_2

Wet O_2 or H_2O

N_2 or Ar

$Q_f \times 10^{11} cm^{-2}$

Temperature °C

$$Q_f(t) = (Q_f(0) - Q_{fe}) \exp\left(-\frac{t}{t}\right) + Q_{fe}$$

- **Ar is a better choice than N_2 for annealing**
- **Q_{fe} is essentially independent of temperature**
- **Q_{it} states can be passivated through hydrogen annealing at fairly low temperatures whereas Q_f is unaffected**

$$H_2 \ ? \quad 2H \text{ followed by } =Si\bullet + H \ ? \ = SiH$$

$$Q_{it} = \frac{Q_{it}(0)}{(1 + kt)^n}$$

- **In large area structures such as MOS capacitors, the diffusion of H_2 can involve significant diffusion times**
- **Polysilicon gates have the advantage of preventing outdiffusion of H_2 ? annealing process is more tolerant of high-T exposure**

**6.5.14 Complete Oxidation Module Simulation**
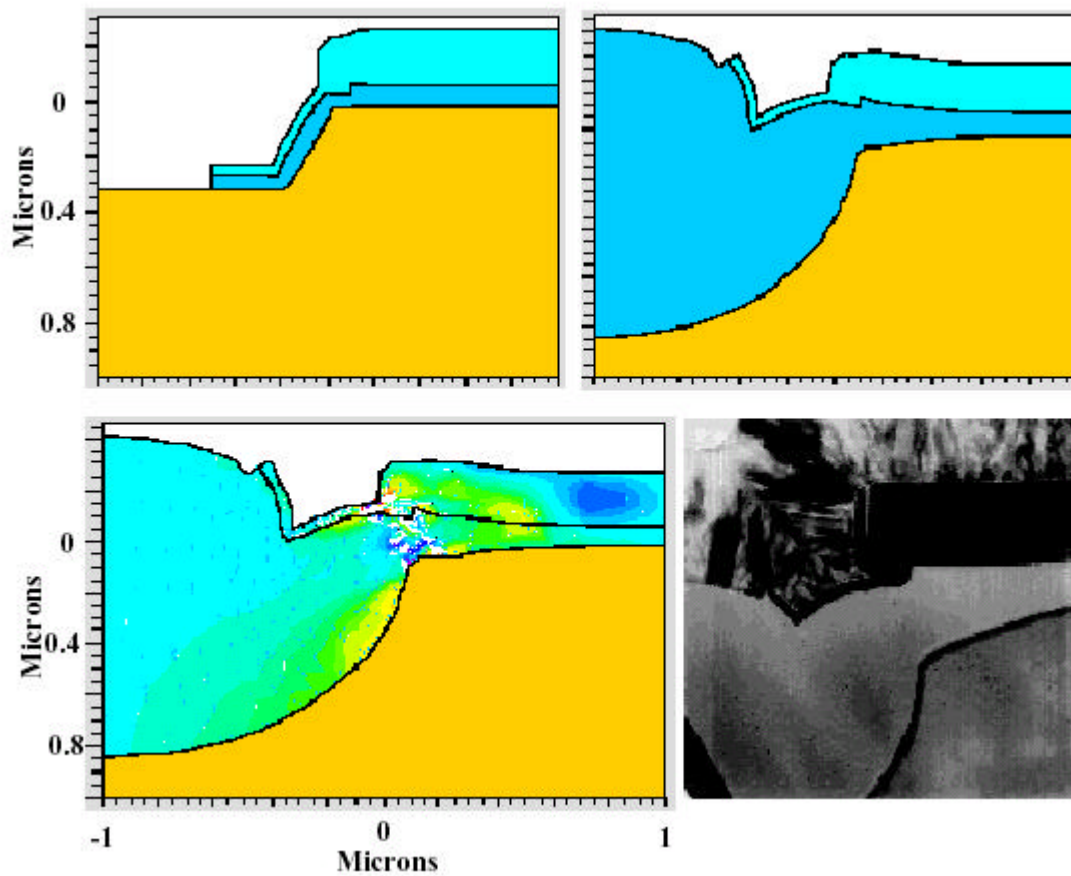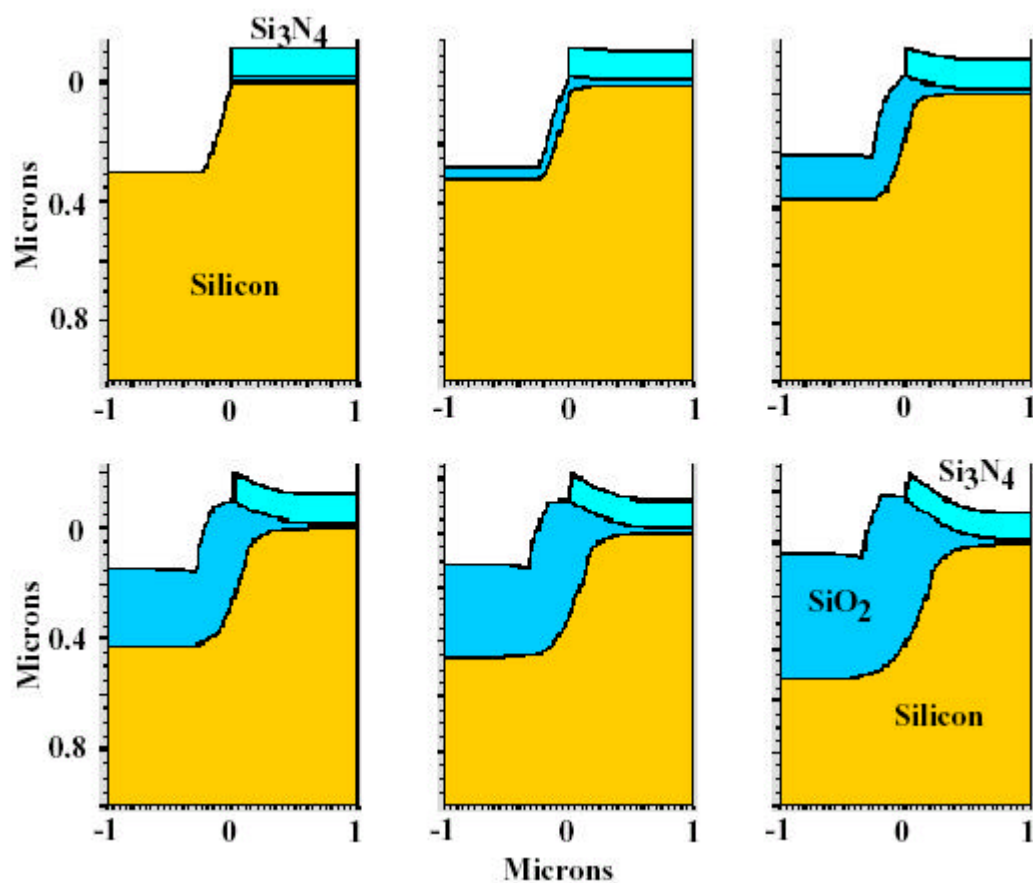
6.6 Limits and Future Trends in Technologies and Models
- **Low T**
- **Low T + high P (10-25 Atm)**
- **The ideal properties of the Si/SiO_2 interface can be preserved with deposited oxides either by first growing a thin thermal oxide and then depositing SiO_2 on top of it or by annealing the deposited oxide**
- **"Composite" dielectric layers**
- **Oxynitride dielectrics by exposing thermally grown SiO2 films to N_2O or NO ambients, or nitrogen implants and subsequent oxidation**
  - **Stronger Si-N bonds ?   resistant to hot carrier stressing**
  - **Resistant to dopant penetration**
  - **Larger K**
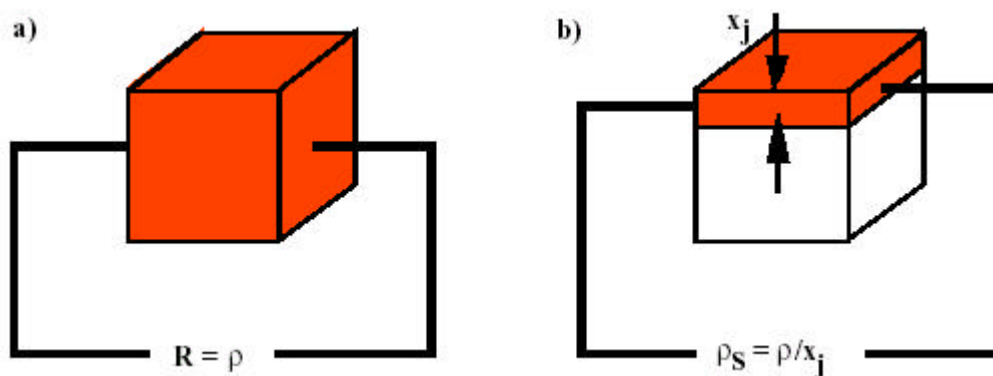- **Change density ~ $10^{10}cm^{-2}$?   one charge / 0.1×0.1μm**

Chap 7. Dopant Diffusion

7.1 Introduction

- **The diffusion cycles required to electrically activate the implanted dopant atoms are often the limiting factor on x_j**
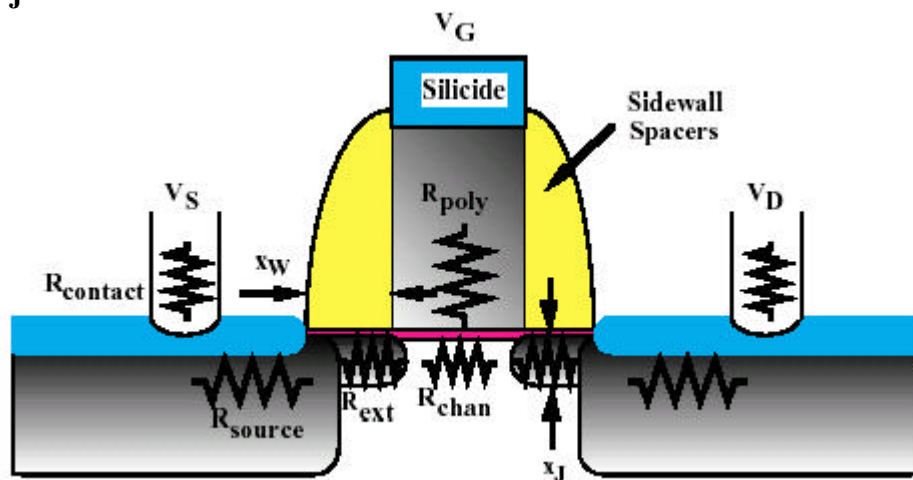
- **May be requirements that the polysilicon gate is doped at the same time that the S/D are formed**

$$J = nqv = nq\mu\epsilon = \sigma\epsilon = \frac{1}{\rho}\epsilon$$

$$\rho = \frac{\epsilon}{J}\,\Omega cm$$

In Fig. 7 - 2 (b),

$$R = \frac{\rho}{x_j}\,\Omega/\text{square} \circ \rho_s$$

$$\rho_s = \frac{1}{\overline{\sigma}x_j} = \frac{1}{q\int_{0}^{x_j}\left[n(x) - N_B\right]\mu\left[n(x)\right]dx}$$

- $R_{contact} + R_{source} + R_{ext} < \dfrac{R_{chan}}{10}$

Year of 1st DRAM Shipment	1997	1999	2003	2006	2009	2012
Min Feature Size (nm)	250	180	130	100	70	50
DRAM Bits/Chip	256M	1G	4G	16G	64G	256G
Minimum Supply Voltage (volts)	1.8-2.5	1.5-1.8	1.2-1.5	0.9-1.2	0.6-0.9	0.5-0.6
Gate Oxide T_{ox} Equivalent (nm)	4-5	3-4	2-3	1.5-2	<1.5	<1.0
Sidewall Spacer Thickness x_W (nm)	100-200	72-144	52-104	20-40	7.5-15	5-10
Contact x_j (nm)	100-200	70-140	50-100	40-80	15-30	10-20
x_j at Channel (nm)	50-100	36-72	26-52	20-40	15-30	10-20
Drain Ext Conc (cm^{-3})	1x10^{18}	1x10^{19}	1x10^{19}	1x10^{20}	1x10^{20}	1x10^{20}

7.2 Historical Development and Basic Concepts

"Predep" controlled dose   Drive-in constant dose

Silicon
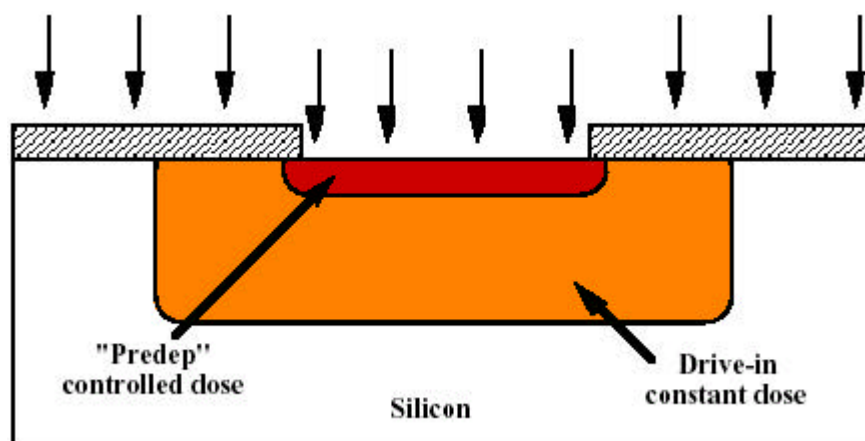
TED (Transient Enhanced Diffusion)

|	Ion Implantation and Annealing	Solid/Gas Phase Diffusion
Advantages	Room temperature mask	No damage created by doping
	Precise dose control	Batch fabrication
	10^{11} - 10^{16} atoms cm^{-2} doses	
	Accurate depth control	
Problems	Implant damage enhances diffusion	Usually limited to solid solubility
	Dislocations caused by damage may cause junction leakage	Low surface concentration hard to achieve without a long drive-in
	Implant channeling may affect profile	Low dose predeps very difficult

7.2.1 Dopant Solid Solubility

Maximum concentration that can be dissolved in Si under equilibrium conditions, without forming a separate phase
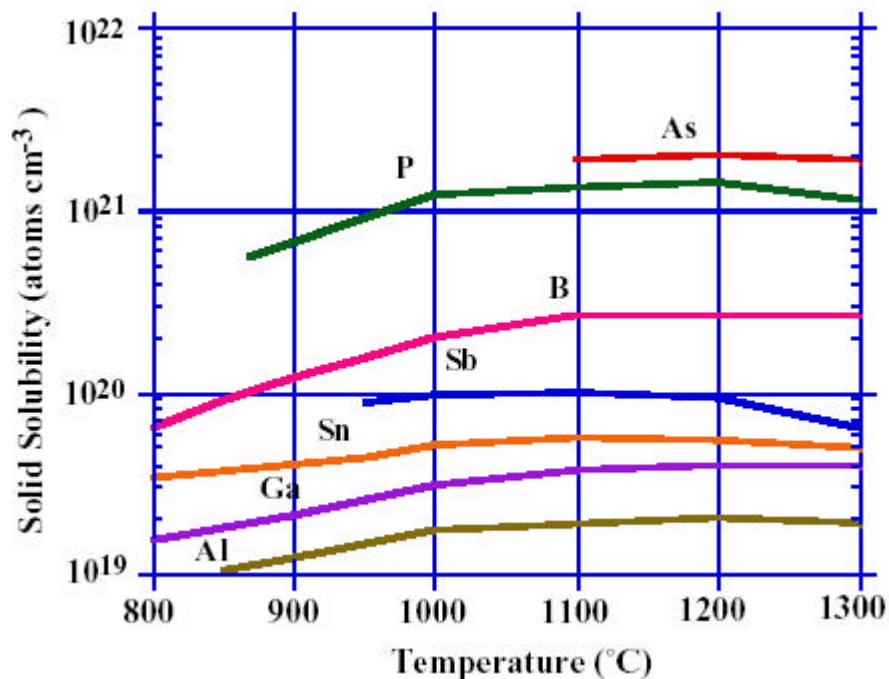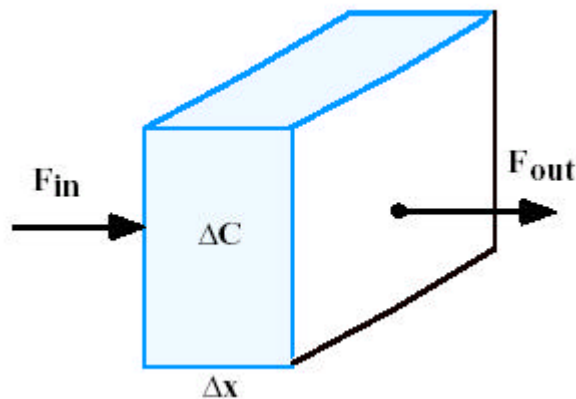
**Electrical solubility limit may be considerably lower than
The maximum solid solubility (neutral cluster formation
With point defects in the Si lattice)**
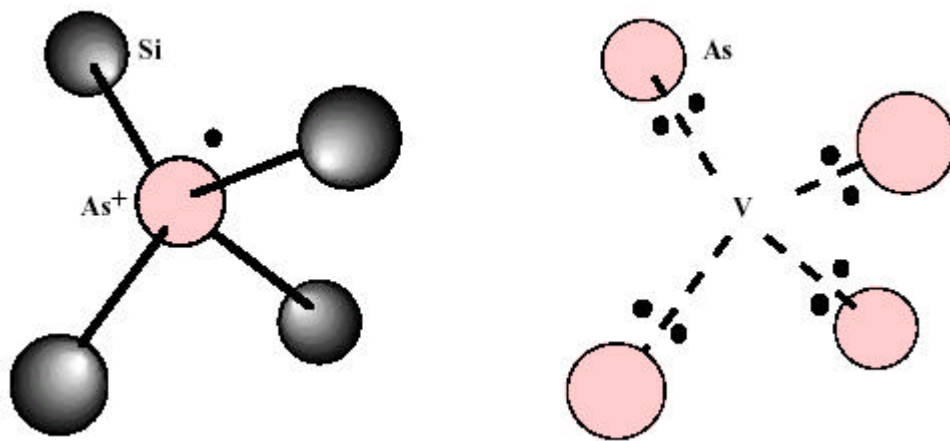
7.2.2 Diffusion from a Macroscopic Viewpoint
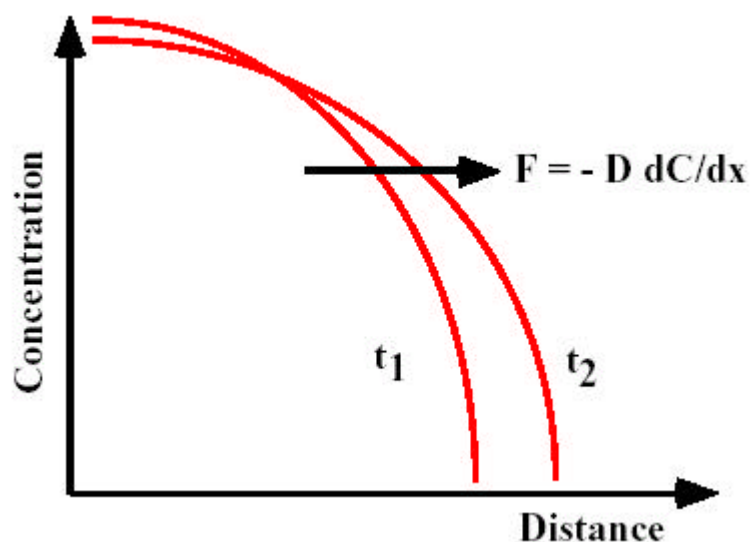
- **Fick's first law :** $F = -D\dfrac{\partial C}{\partial x}$

- **In a diamond lattice (Si, GaAs) which has cubic symmetry, D has the same value in all directions**

- **Fick's second law**

$$\frac{\partial C}{\partial t} = \frac{\partial F}{\partial x} = \frac{F_{in} - F_{out}}{\partial x}$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right)$$

- **If D is a constant**

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

$$\frac{\partial C}{\partial t} = -\tilde{\nabla}\cdot F = \tilde{\nabla}\cdot(D\tilde{\nabla}C)$$
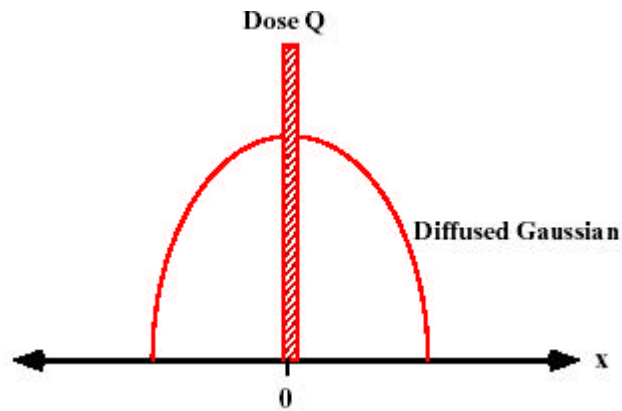
7.2.3 Analytic Solutions of the Diffusion Equation
- **Steady-state**

$$D\frac{\partial^2 C}{\partial x^2} = 0$$

$$C = a + bx$$

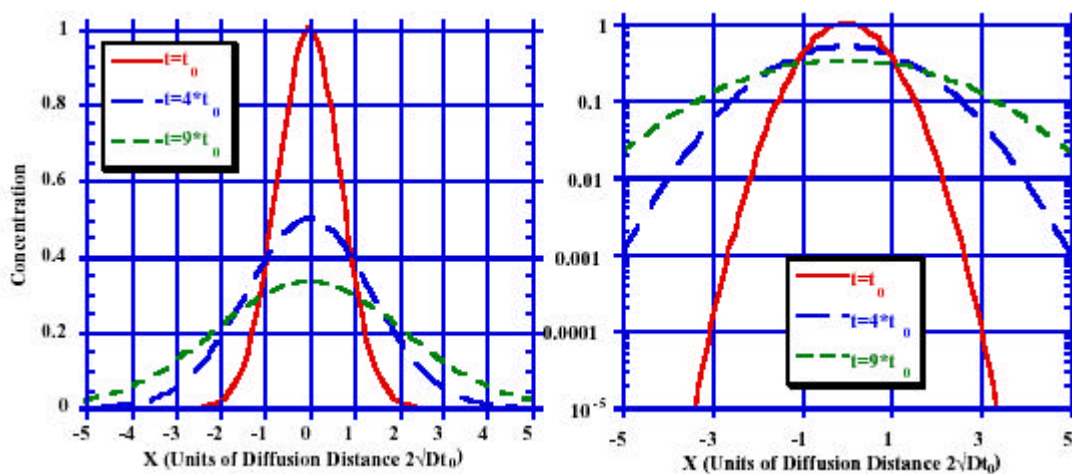# 7.2.4 Gaussian Solution in an Infinite Medium

C → 0 as t → 0 for x > 0

C → ¥ as t → 0 for x = 0

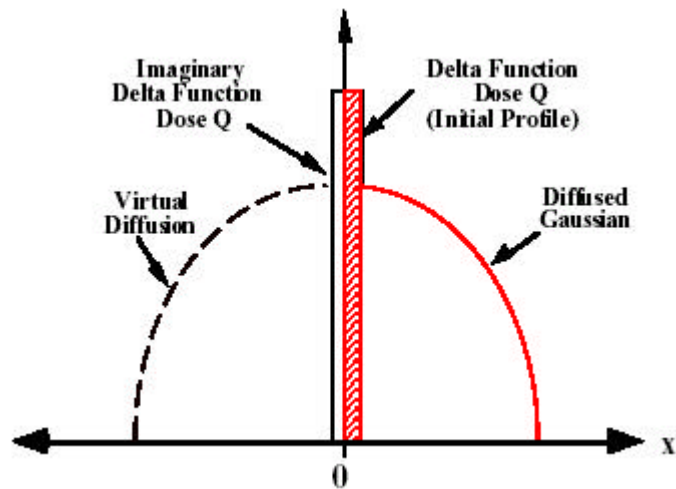$$\int_{-\infty}^{\infty} C(x,t)dt = Q$$

$$C(x,t) = \frac{Q}{2\sqrt{\pi Dt}}\exp\left(-\frac{x^2}{4Dt}\right) = C(0,t)\exp\left(-\frac{x^2}{4Dt}\right)$$

The peak concentration decreases as $\dfrac{1}{\sqrt{t}}$ **and is given by C(0,t)**

When $x = 2\sqrt{Dt}$, **the surface concentration has fallen by** $\dfrac{1}{e}$
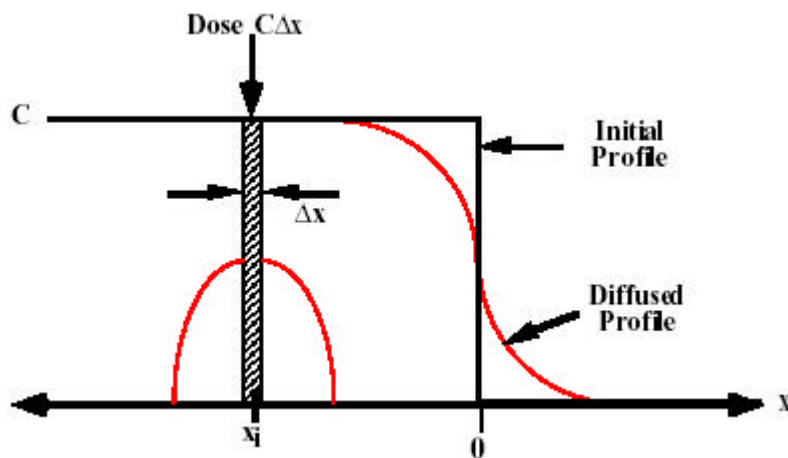
7.2.5 Gaussian Solution near a Surface

Assumption : no dopant is lost through evaporation or segregation during the anneal

Effectively a dose of 2Q is introduced into an infinite medium

$$C(x,t) = \frac{Q}{\sqrt{\pi Dt}} \exp\left(-\frac{x^2}{4Dt}\right) = C(0,t) \exp\left(-\frac{x^2}{4Dt}\right)$$

$$C(0,t) = \frac{Q}{\sqrt{\pi Dt}}$$

7.2.6 Error-Function Solution in an Infinite Medium

$$C = 0 \text{ at } t = 0 \text{ for } x > 0$$
$$C = C \text{ at } t = 0 \text{ for } x < 0$$

The problem is made up by a sum of the previous Gaussian solutions

$$C(x,t) = \frac{C}{2\sqrt{\pi Dt}} \sum_{i=1}^{n} \Delta x_i \exp - \frac{(x - x_i)^2}{4Dt}$$

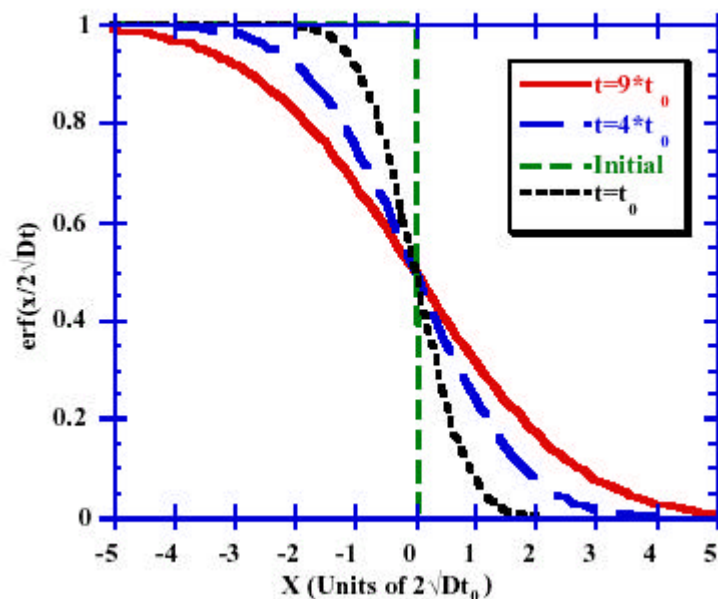$$C(x,t) = \frac{C}{2\sqrt{\pi Dt}} \int_{-\infty}^{0} \exp - \frac{(x - a)^2}{4Dt} d$$

$$\frac{x - a}{2\sqrt{Dt}} = h$$

$$C(x,t) = \frac{C}{\sqrt{\pi}} \int_{\frac{x}{2\sqrt{Dt}}}^{0} \exp(- h^2) dh$$

$$erf(z) = \frac{2}{\sqrt{\pi}} \int_{0}^{z} \exp(- h^2) dh$$

$$C(x,t) = \frac{C}{2} \left[1 - erf \left(\frac{x}{2\sqrt{Dt}} \right) \right]$$

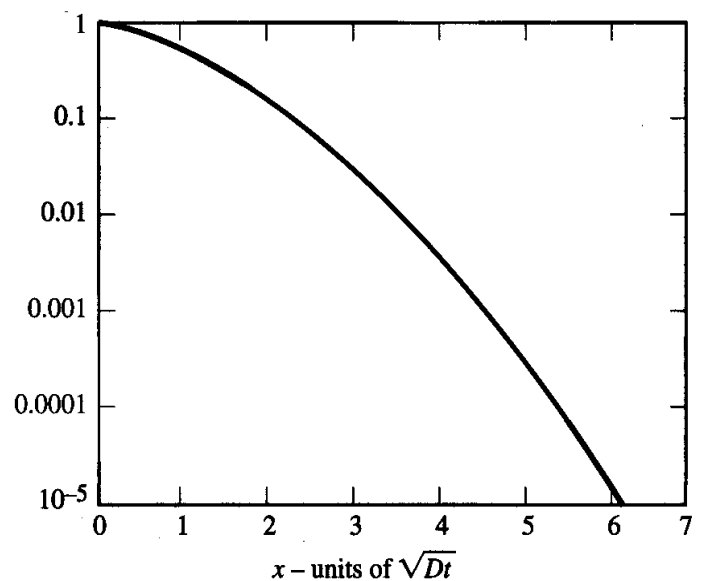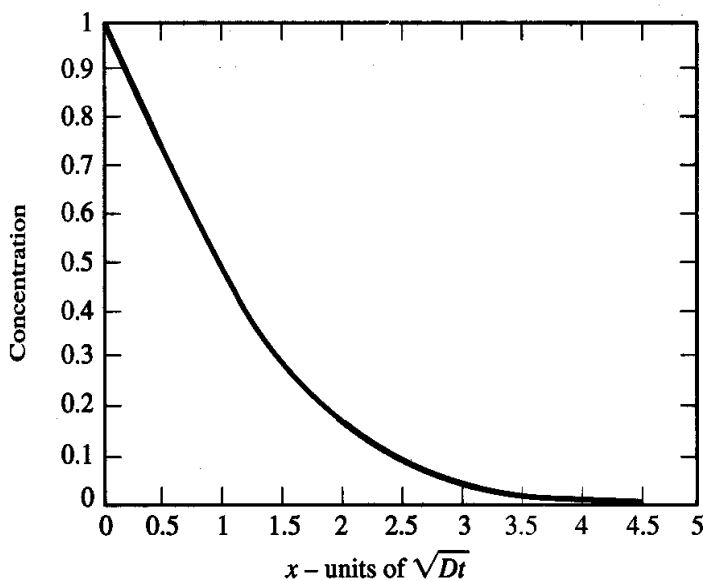$$= \frac{C}{2} \left[erfc \left(\frac{x}{2\sqrt{Dt}} \right) \right]$$
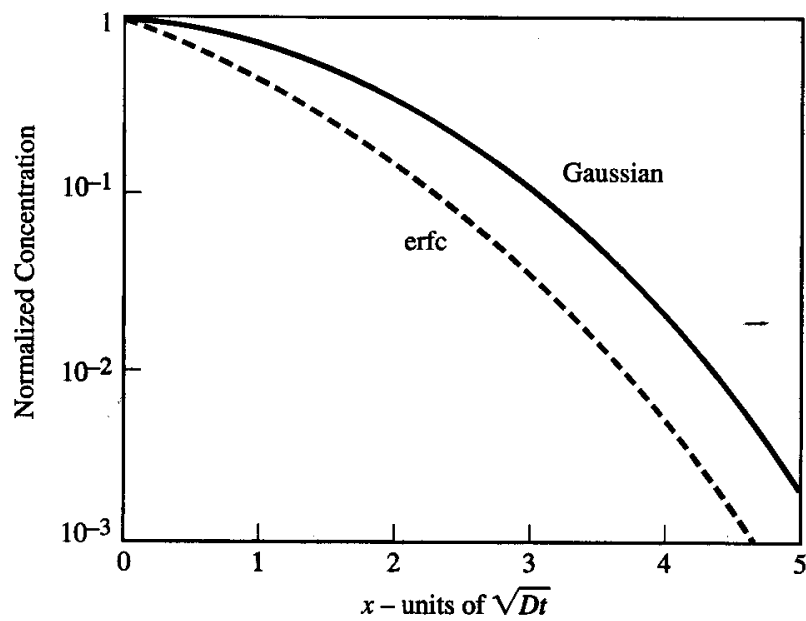
7.2.7 Error-Function Solution near a Surface
- **Constant surface concentration at all times**
- **The midpoint in Fig.7-12 must remain stationary**

$$C(x,t) = C_s \left[erfc \frac{x}{2\sqrt{Dt}} \right]$$

x – units of $\sqrt{Dt}$

x – units of $\sqrt{Dt}$

- **The error-function solution is (very approximately) triangular on a linear scale** ® $Q = C_s\sqrt{Dt}$

  More accurately,

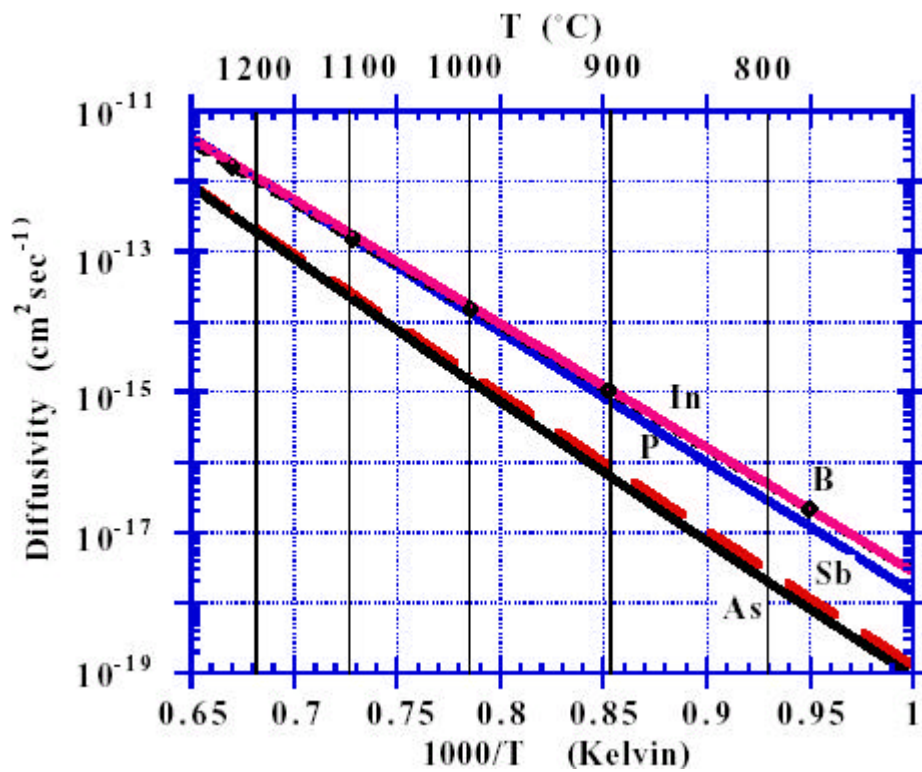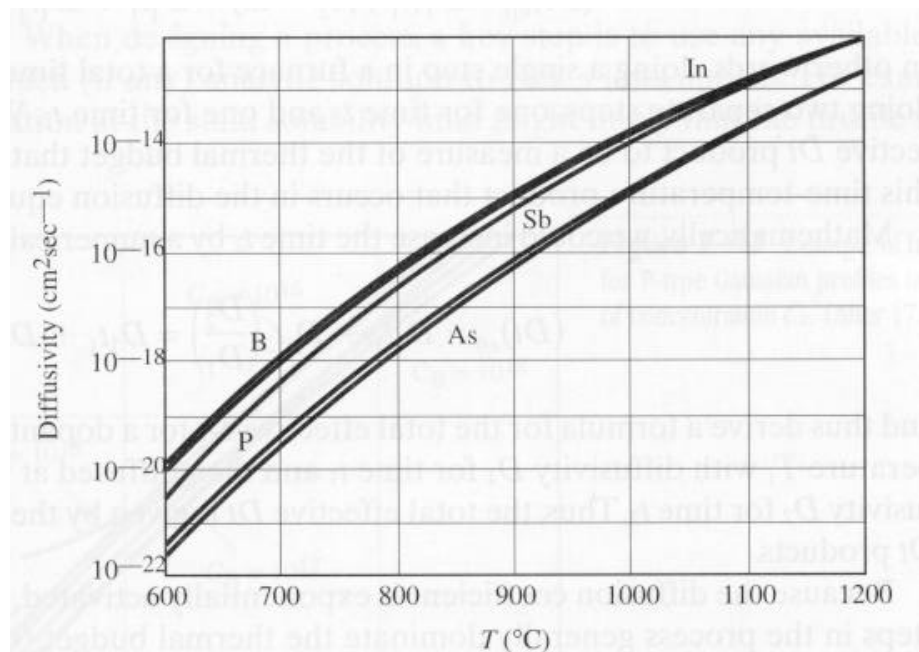$$Q = \int_0^\infty C_s \left[1 - erf \left(\frac{x}{2\sqrt{Dt}} \right) \right] dx = \frac{2C_s}{\sqrt{p}} \sqrt{Dt}$$

7.2.8 Intrinsic Diffusion Coefficients of Dopants in Silicon

$$D = D^{\circ} \exp\left(\frac{-E_A}{kT}\right)$$

$$E_A = 3.5 - 4.5eV$$

Diffusivity (cm²sec⁻¹) vs T (°C) plot showing curves labeled In, Sb, As, B, P.

Table 7–3	Intrinsic diffusivity in $cm^2 sec^{-1}$ for silicon self-diffusion and of common dopants in single-crystal silicon, fitted to an Arrhenius expression						
	Si	B	In	As	Sb	P	Units
D^0	560	1.0	1.2	9.17	4.58	4.70	$cm^2\ sec^{-1}$
E_A	4.76	3.5	3.5	3.99	3.88	3.68	eV

- " Slow" diffusers : As, Sb
  " Fast" diffusers : P, B, In
- Under extrinsic conditions, all dopants show much higher D

7.2.9 Effect of Successive Diffusion Steps
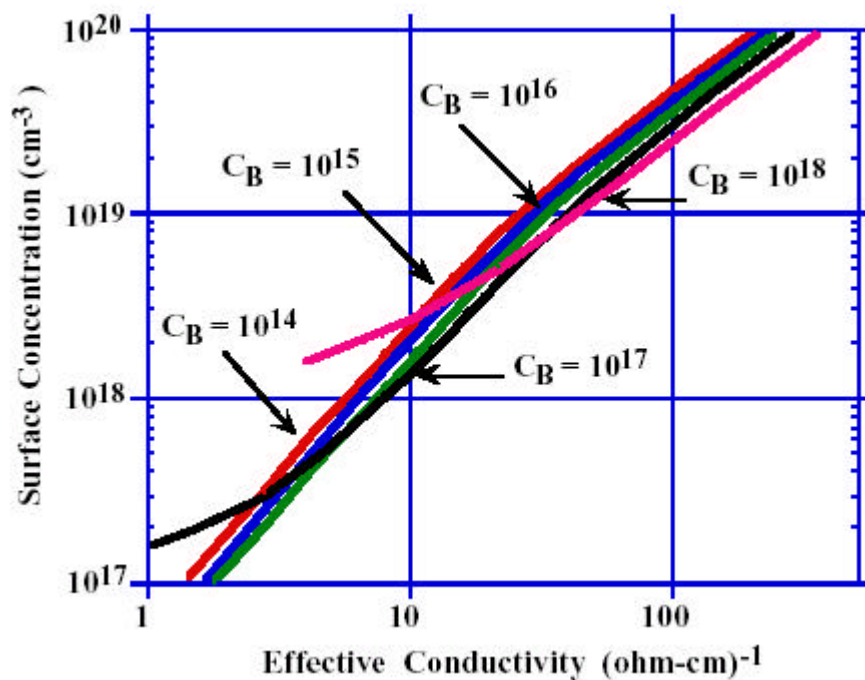 • If all the diffusion steps occurred at a constant temperature

$$(Dt)_{eff} = D_1(t_1 + t_2 + \cdots) = D_1t_1 + D_1t_2 + \cdots$$

$$(Dt)_{eff} = D_1t1 + D_1t_2\left(\frac{D_2}{D_1}\right) = D_1t_1 + D_2t_2$$

$$t_2^{equiv} = t_1 \cdot \frac{D_1}{D_2}$$

7.2.10 Design and Evaluation of Diffused Layers
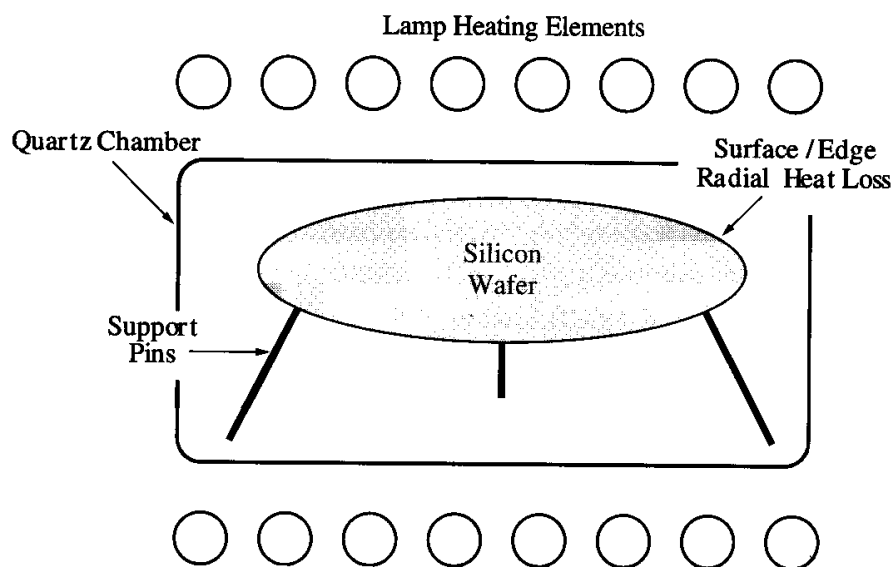 • Sheet resistance, surface concentration, junction depth
 • Invin's curves

7.2.11 Summary of Basic Diffusion Concepts

7.3 Manufacturing Methods and Equipment

- **Important to have some oxide or other capping layer to prevent evaporation of the dopant**
- **Anneals are often performed in a low partial pressure of oxygen sufficient to grow a thin oxide layer or are performed with a reasonable thickness of oxide present**
- **Idle at a temperature between 750-800°C**
- **Ramps slowly (5-10°C min^{-1}) to the final anneal T**
- **After a diffusion step, ramp down to the idling T**
- **Oxidation can alter D through OED**
- **If the dopants are introduced by ion implantation, the can end up diffusing more at lower T because the ion-implantation-induced defects last longer and continue to enhance D**
- **Modern devices often use a thermal cycle simply to electrically activate implanted dopant atoms and process designers would often be very happy if no diffusion took place during this step**
 - **? RTA (Rapid Thermal Annealing)**

Lamp Heating Elements

Quartz Chamber

Surface /Edge Radial Heat Loss

Silicon Wafer

Support Pins

• **Ramp rates ~ 100°C/sec**

Table 7-4 Summary of furnace and RTA diffusion and annealing system characteristics	
Furnace	**RTA**
Batch	Single wafer
Long time	Short time
Slow ramp	Fast ramp
Long stabilization	Short steady state
Excellent temperature control	Accurate temperature control difficult

• **A silicon wafer subject to incident radiation will achieve a uniform temperature across and through the wafer in a few msecs**
• **Even if there is a perfectly uniform incident radiation flux, the wafer edges will be color (heat loss)**
  ? may cause slip
     suppressed by surrounding the wafer a polysilicon slip ring
     multiple circular zones of lamps
• **Monitoring temperature**
     Thermocouple
     Optical pyrometry

7.4 Measurement Methods

## 7.4.1 SIMS (= Secondary Ion Mass Spectrometry)
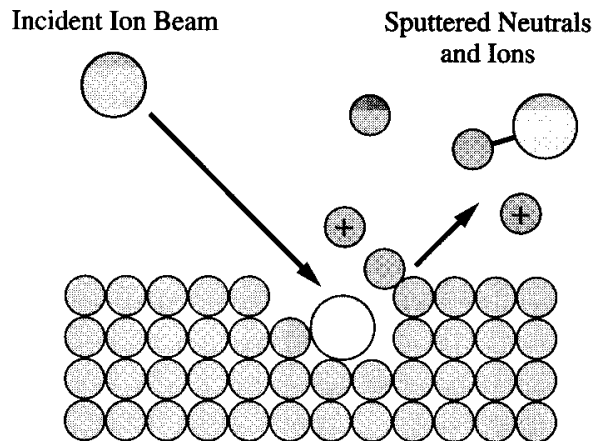
- **Special SIMS test areas, which are large squares(200× 200μm), are often incorporated**
- **This large area is physically sputtered, and the ions are collected from a smaller, central probe area to minimize edge effects**
- **Accelerated ? mass analyzed ? counted**
- **The incident ion beam is chosen to produce a high yield and a small mass interference due to unintentional ion complexing**
- **n - type dopants : C_s ⇑**
  p - type dopants : O ⇓ high yield
- **Sensitivity : 10^{16}-10^{17}/cm^3**

- ⎡ Cs : heavy ? "knock on" ? degrade the resolution
- ⎣ O : light ? minimize "knock on" problem
  - but, a higher background floor
- May be unreliable in ultrashallow
- O : the initial rate may be higher
  - ? low energy (200eV to 5 keV)
- "Matrix effect" (each different layer in the matrix has its own unique ion yield)
- Cs : can lead to "mixing" of layers when puttering through ultrathin layers
- Mixing effects can be minimized by using a low energy and shallow angle of incidence
- Sputter neutral mass spectrometry

7.4.2 Spreading Resistance
- Electrical measurement using a pair of fine metal probes
- By measuring the resistivity and comparing it against resistivity standards ? N can be obtained

Original Surface

Osmium Probes

S

$2\,\mu m$ $25\,\mu m$

Δx

$\Delta x = S \sin \phi$

ϕ

Beveled Surface
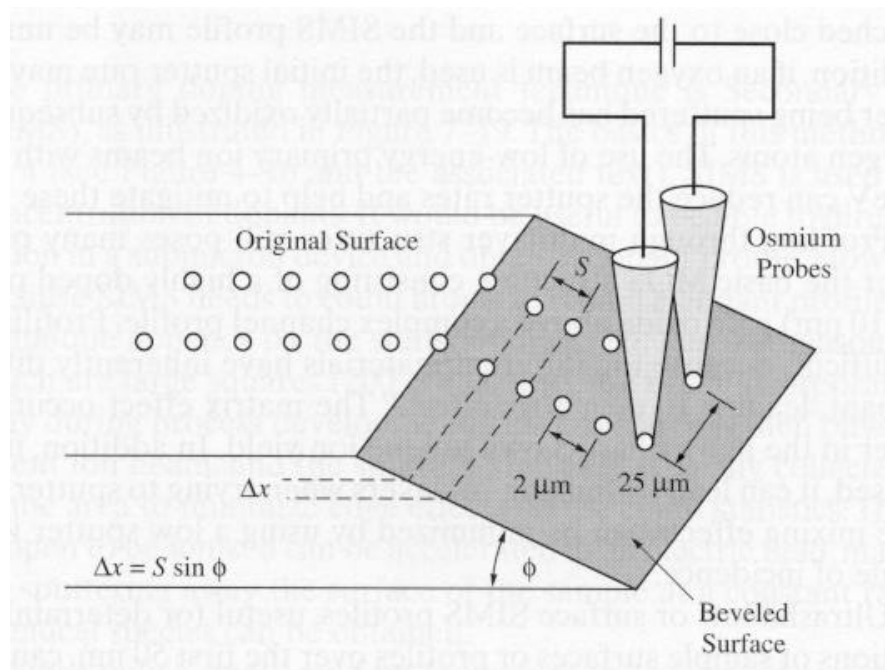
- **Beveling : gluing a small sample to a precision-machined holder**
    - **? polished using a diamond slurry and a rotating wheel**
- **Important : the probes make good electrical contact yet not penetrate too deeply into the bulk**
- **SIMS : chemical**

    Spreading resistance : electrical $\Big\rangle$ **differnece correspond s to**

    dopants which are not electrically active

7.4.3 Sheet Resistance

- **Provide an integrated electrical conductivity over the whole profile**
- **4 probes** $\Big[$ **outer 2 : force a current**
    inner 2 : measure a voltage
- **For shallow junctions, the mechanical probes penetrate too deeply**
    - **? Van der Pauw**

7.4.4 Capacitance Voltage

$$C \ ? \ x_D ? \ N$$

7.4.5 TEM Cross Section
- **TEM, electrical inverse methods, direct CV, Kelvin probe**

Poly gate

Gate oxide

Diffused junction
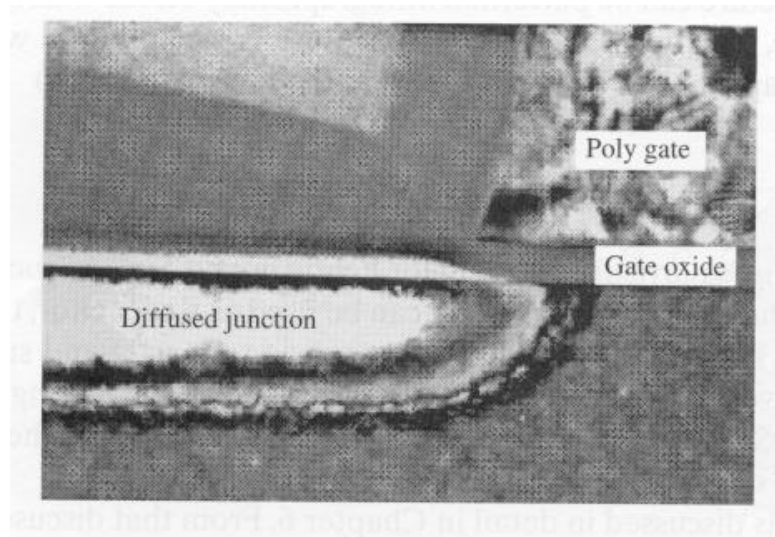
- **HF : HNO$_3$: CH$_3$COOH (1 : 40 : 20)**
  - dilutant
  - oxidizes the Si
  - dissolves the oxide
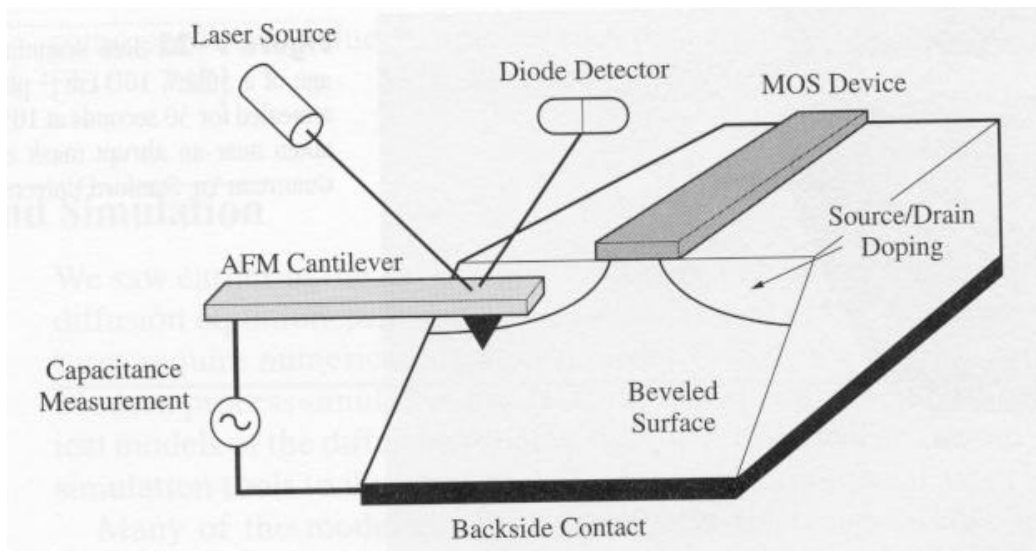- **The etch rates depend on N and appear to similar for n-type and p-type**

7.4.6 2D Electrical Measurements Using Scanning Probe Microscopy

- **Average distance**
  - **= 1.3nm at 10^{20}cm^{-3}**
  - **= 6.2nm at 10^{18}cm^{-3}**
  - **= 28.8nm at 10^{16}cm^{-3}**

- **Scanning probe method ? STM (Scanning Tunneling Microscope)**
- **Scanning capacitance and scanning resistance probes**

- **Cross-sectional samples must be prepared**
- **The surface of the Si cross section or metal probe must be coated with an oxide layer**
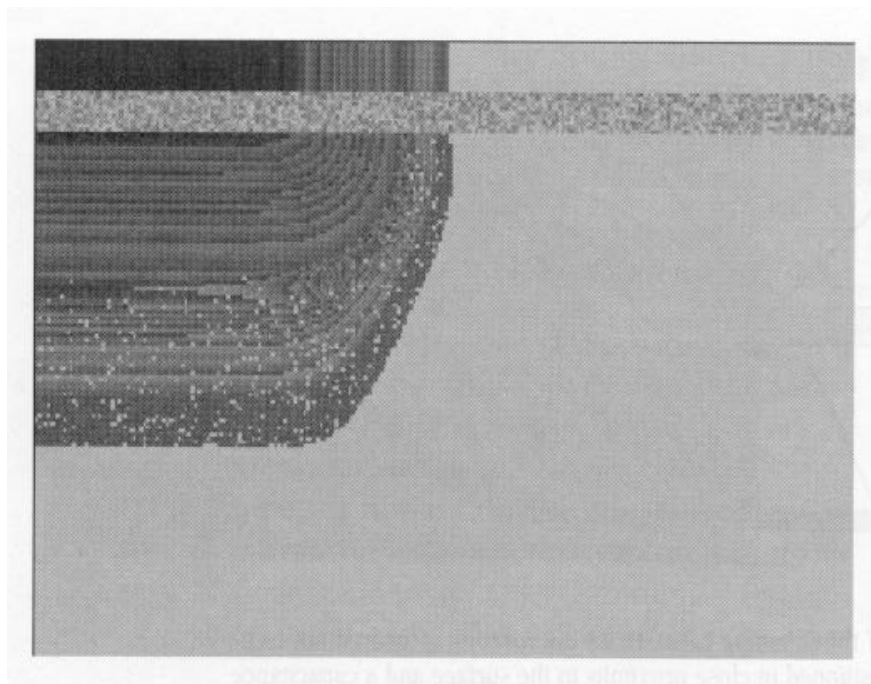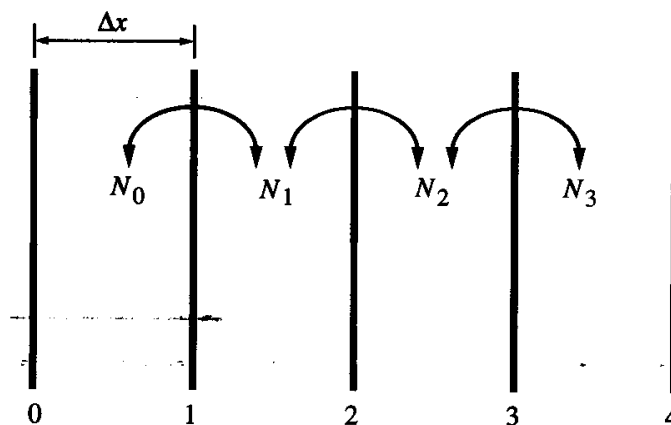
- **SRP**
- **Workfunction measurement ?   N**

7.4.7 Inverse Electrical Measurements
- **IV or CV⟵⟶ simulation results
          compared**
- **The doping profiles are varied until they match**

7.5 Models and Simulation

7.5.1 Numerical Solutions of the Diffusion Equation

$$C_i = N_i \, ? \, x / cm^3$$

- **The atoms remain relatively fixed in the lattice but vibrate at the Debye frequency ($10^3 sec^{-1}$)**

- **The frequency of hopping**

$$v_b = v_d \exp\left(-\frac{E_b}{kT}\right)$$

Debye frequency

$$\left(\frac{v_b}{2}\right)N \quad \text{jumping right}$$

$$\left(\frac{v_b}{2}\right)N \quad \text{jumping left}$$

$$F = -\frac{v_b}{2}\left(N_2 - N_1\right) = -\frac{v_b}{2}\Delta x(C_2 - C_1) = -\frac{v_b}{2}\Delta x^2 \frac{\Delta C}{\Delta x}$$

$$= -D\frac{\Delta C}{\Delta x}$$

Where $D = \dfrac{v_b}{2}\Delta x^2$

- **At plain i**

$$N_i^+ = N_i + \frac{v_b}{2}\Delta t(N_{i-1} - 2N_i + N_{i+1})$$

$$C_i^+ = C_i + \frac{v_b}{2}\Delta t(C_{i-1} - 2C_i + C_{i+1})$$

$$C_i^+ = C_i + \frac{D\Delta t}{\Delta t^2}(C_{i-1} - 2C_i + C_{i+1})$$

- **A simplification of this equation ;**

$$\frac{D\Delta t}{\Delta x^2} = \frac{1}{2}$$

$$C_i^+ = \frac{1}{2}(C_{i-1} + C_{i+1})$$

- If $\dfrac{D\Delta t}{\Delta x^2} > 0.5$ ® the solution becomes unstable

- $\dfrac{D\Delta t}{\Delta x^2} = 0.5$ represents the maximum value

7.5.2 Modification to Fick's Laws to Account for Electric Field Effects

- **When N>n_i, e-fields set up by the dopants can affect the diffusion process**
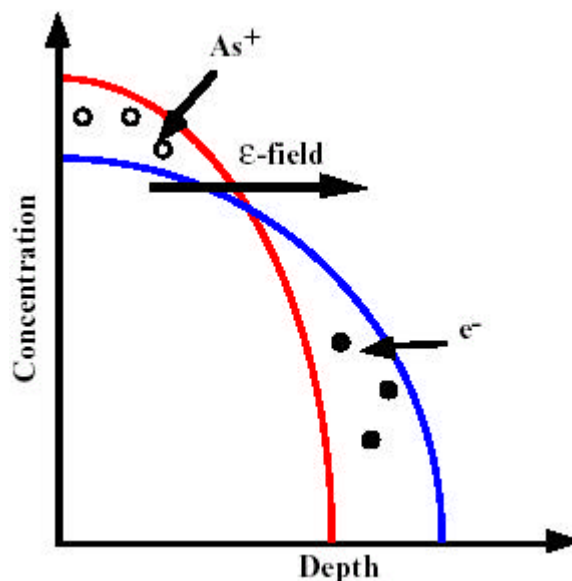   - ? **Additional flux or flow of species F'=Cv**

velocity of particles

$$F_{total} = F + F' = -D\frac{\partial C}{\partial x} + Cv$$

- **If F' and v are independent of x,**

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) - v\frac{\partial C}{\partial x}$$

- **The origin of the field comes from the higher mobility of electrons and hoes compared to dopants**

$$v = \mu\varepsilon$$

$$\varepsilon = \frac{\partial\psi}{\partial x}$$

$$\psi = -\frac{kT}{q}\ln\frac{n}{n_i}$$

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

$$F = -D\frac{\partial C}{\partial x} - DC\frac{\partial}{\partial x}\ln\frac{n}{n_i}$$

$$= -DC\frac{\partial}{\partial x}\ln\left(C\frac{n}{n_i}\right)$$

- **The flux can be expressed in terms of N only, if charge neutrality and Boltzmann statistics apply**

$$N_D^+ + P = N_A^- + n$$

$$np = n_i^2$$

If $N_D^+ \approx N_D$ and $N_A^+ \approx N_A$ the flux can be written as

$$F = -hD\frac{\partial C}{\partial x}$$
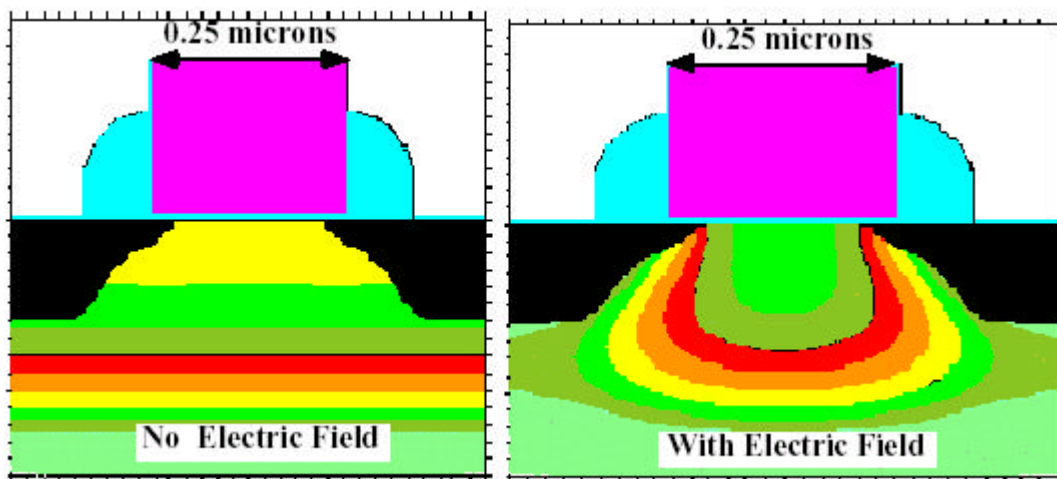
where $C = |N_D - N_A|$

$h =$ electric field enhancement factor
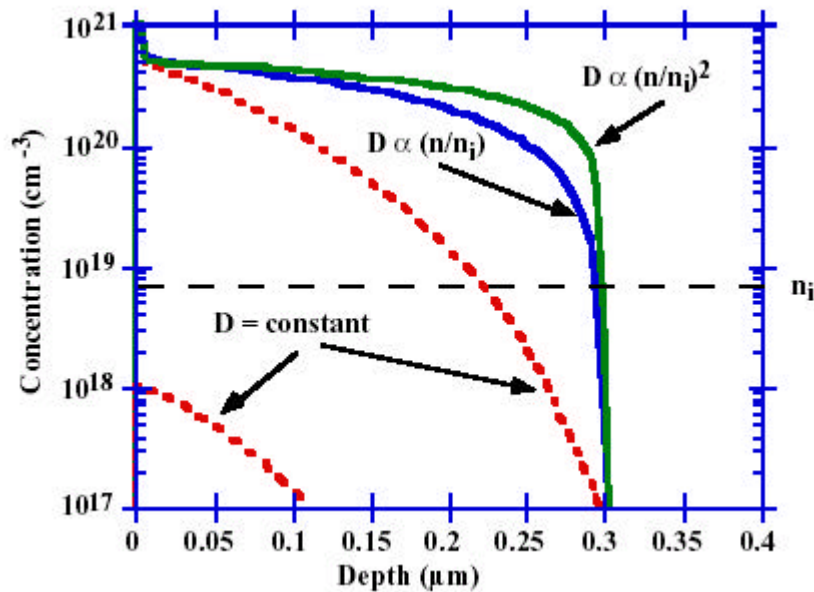
$$\circ\; 1 + \frac{C}{\sqrt{C^2 + 4n_i^2}}$$

h has an upper bound of 2
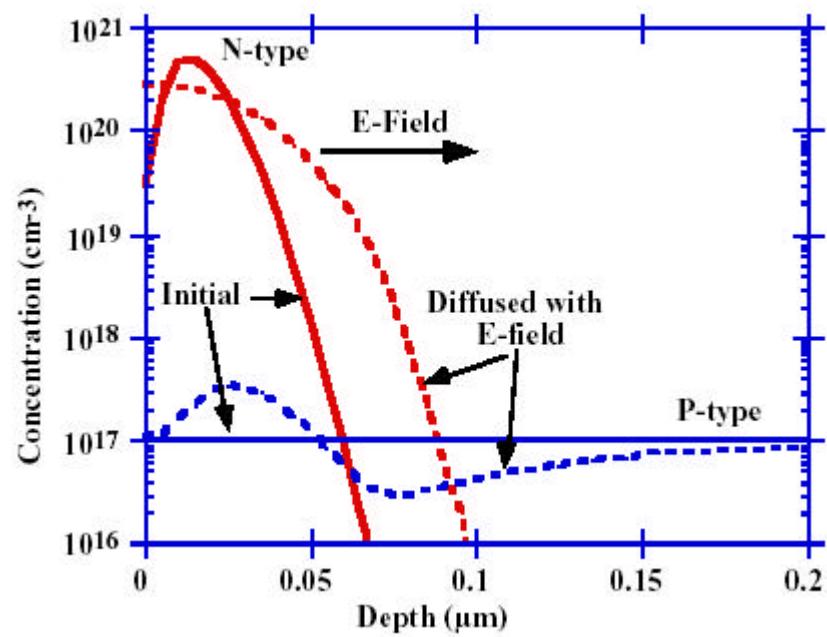
• **Bigger changes in D of a low-concentration dopant**

7.5.3 Modifications to Fick's Laws to Account for Concentration-Dependent Diffusion

- **The diffusivity varies with concentration, with the higher-concentration regions diffusing faster**

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D_A^{eff} \frac{\partial C}{\partial x} \right)$$

- **Experiment ally,** $D \, \alpha \left(\dfrac{n}{n_i} \right)$ **or** $D \, \alpha \left(\dfrac{n}{n_i} \right)^2$

$$D_A^{eff} = D^0 + D^-\left(\frac{n}{n_i} \right) + D^=\left(\frac{n}{n_i} \right)^2 \quad \text{for Ntype dopants}$$

$$D_A^{eff} = D^0 + D^+\left(\frac{P}{n_i} \right) + D^{++}\left(\frac{P}{n_i} \right)^2 \quad \text{for Ptype dopants}$$
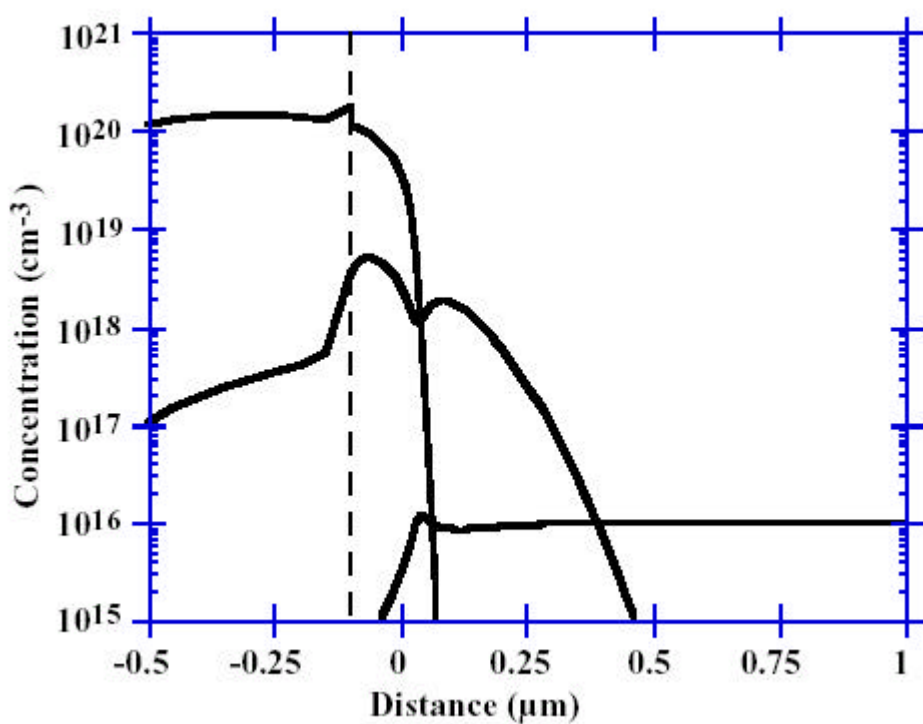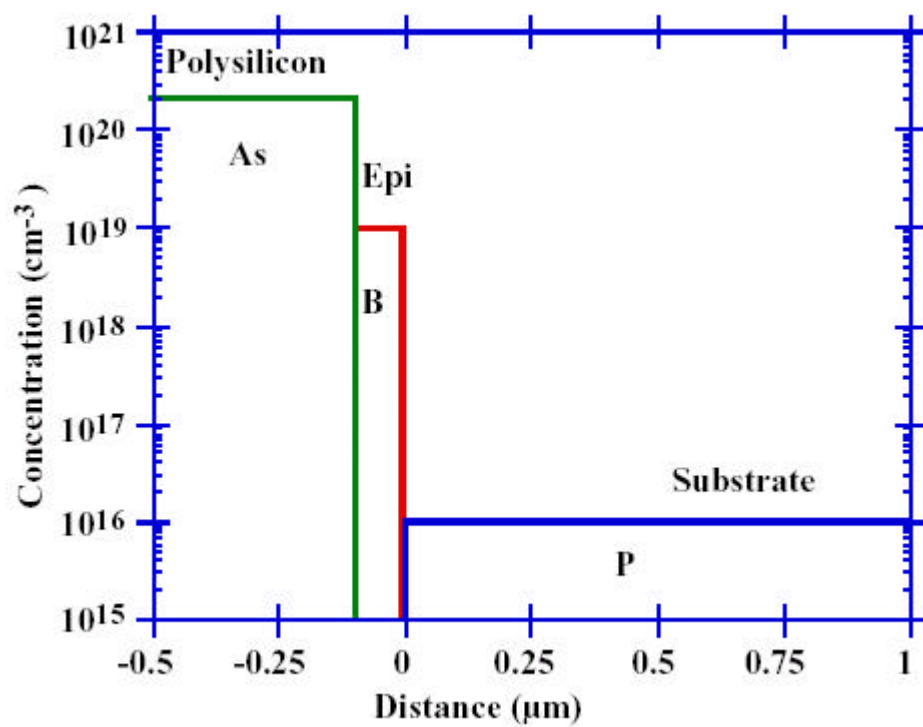
- **Intrinsic Conditions**

$$D_A^* = D^0 + D^- + D^=$$

$$D = D.0 \exp\left(- \frac{D.E}{kT}\right)$$

- $$D_A^{eff} = D_A^* \left[\frac{1 + b\dfrac{n}{n_i} + g\left(\dfrac{n}{n_i}\right)^2}{1 + b + g} \right]$$

  where $\quad b = \dfrac{D^-}{D^0} \quad$ and $\quad g = \dfrac{D^=}{D^0}$

	Si	B	In	As	Sb	P
$D^0.0$ cm^{2}sec^{-1}	560	0.05	0.6	0.011	0.214	3.85
$D^0.E$ eV	4.76	3.5	3.5	3.44	3.65	3.66
$D^+.0$ cm^{2}sec^{-1}		0.95	0.6			
$D^+.E$ eV		3.5	3.5			
$D^-.0$ cm^{2}sec^{-1}				31.0	15.0	4.44
$D^-.E$ eV				4.15	4.08	4.0
$D^=.0$ cm^{2}sec^{-1}						44.2
$D^=.E$ eV						4.37

Top figure (x-axis: Distance (μm), y-axis: Concentration (cm⁻³)):

10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}

Polysilicon
As
Epi
B
Substrate
P

-0.5   -0.25   0   0.25   0.5   0.75   1

Bottom figure (x-axis: Distance (μm), y-axis: Concentration (cm⁻³)):

10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}

-0.5   -0.25   0   0.25   0.5   0.75   1

7.5.4 Segregation

- **Dopants have different solubilities in different materials**
  - **? redistribute at an interface until the chemical potential is the same**
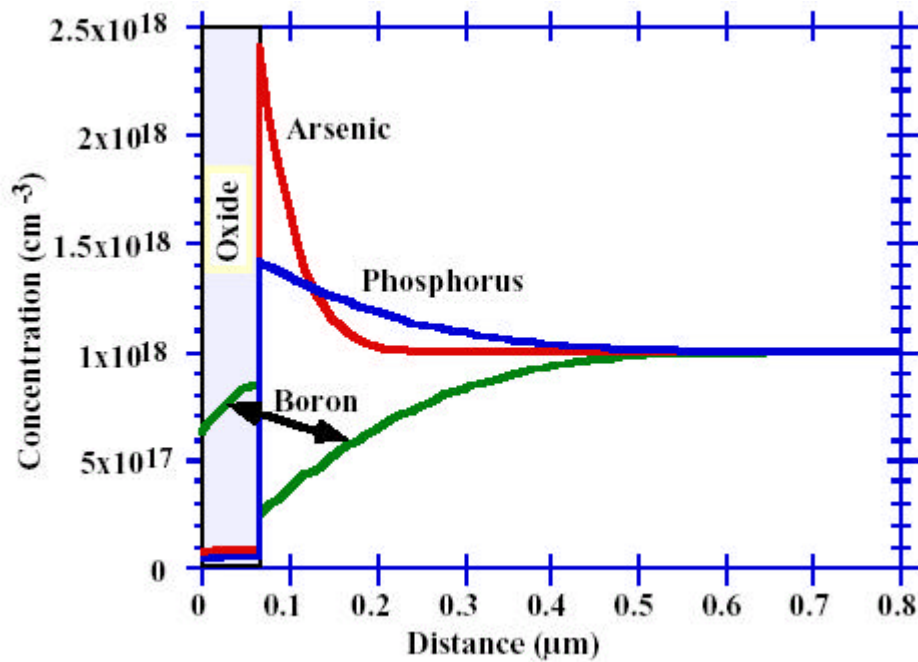- **Segregation coefficient = ratio of the equilibrium doping concentration on each side of the interface**

$$X_A \overset{k_1}{\underset{k_2}{\longleftrightarrow}} X_B$$
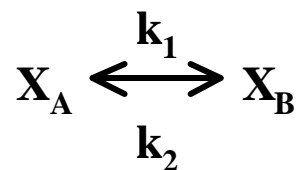
$$F_{AB} = k_1 C_A - k_2 C_B$$

In steady state, $F_{AB} = 0 \Rightarrow \dfrac{C_B}{C_A} = \dfrac{k_1}{k_2} = k_0 = $ segregation coefficient

$$\therefore F = k_1 \left(C_A - \frac{C_B}{k_0} \right) = h\left(C_A - \frac{C_B}{k_0} \right)$$
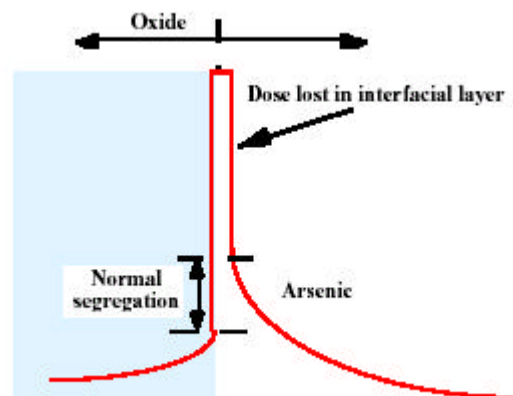
$$k_0 = \frac{C_{si}}{C_{sio_2}} \approx \begin{cases} 0.3 \text{ for B} \\ 10 \text{ for As, Sb, P} \end{cases}$$
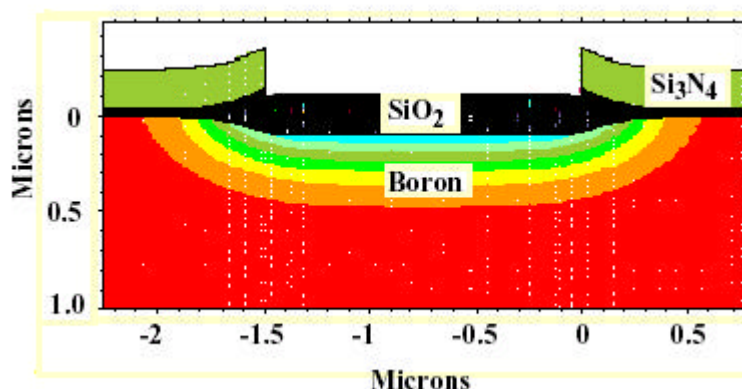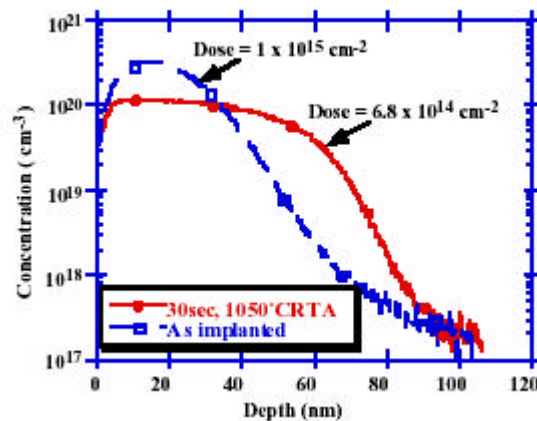
- **As profile is steeper than the P profile because of smaller diffusivity**
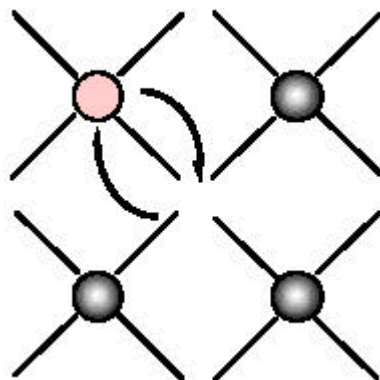
7.5.5 Interfacial Dopant Pileup

• **The interfacial layer may be as thin as a monolayer and can act as a sink for dopant atoms and is able to trap on the order of an atomic layer of dopant**
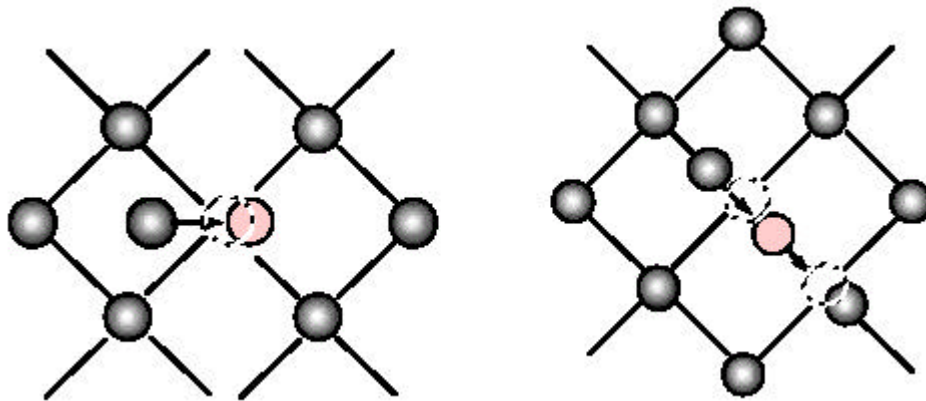

• **It occurs on the same time scale as the rapid thermal cycles**

7.5.6 Summary of the Macroscopic Diffusion Approach

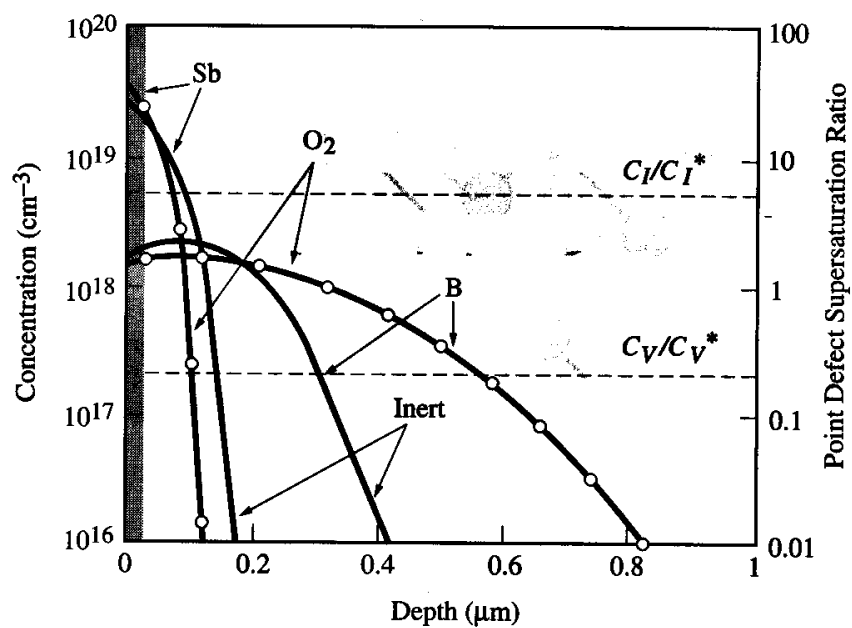## 7.5.7 The Physical Basic for Diffusion at an Atomic Scale


Vacancy-assisted diffusion

Interstitial-assisted ⌈ **kick-out**
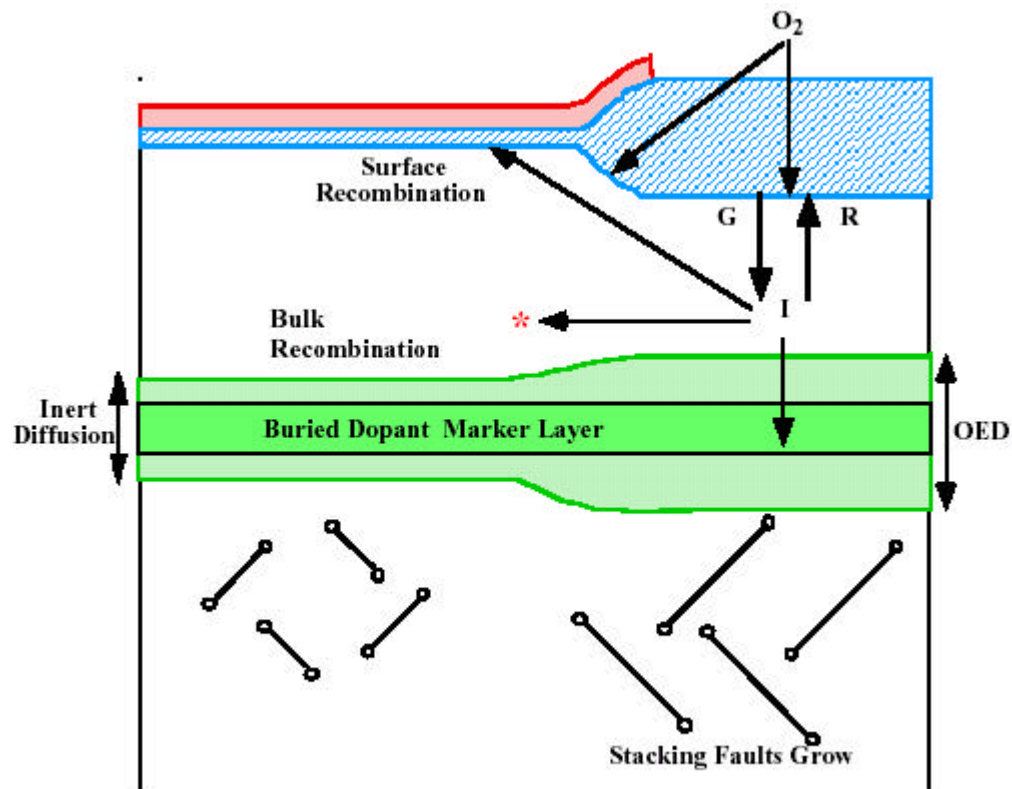⌊ **interstitialcy**

7.5.8 Oxidation-Enhanced or –Retarded Diffusion
 • **P, B : Oxidation-enhanced diffusion (OED)**
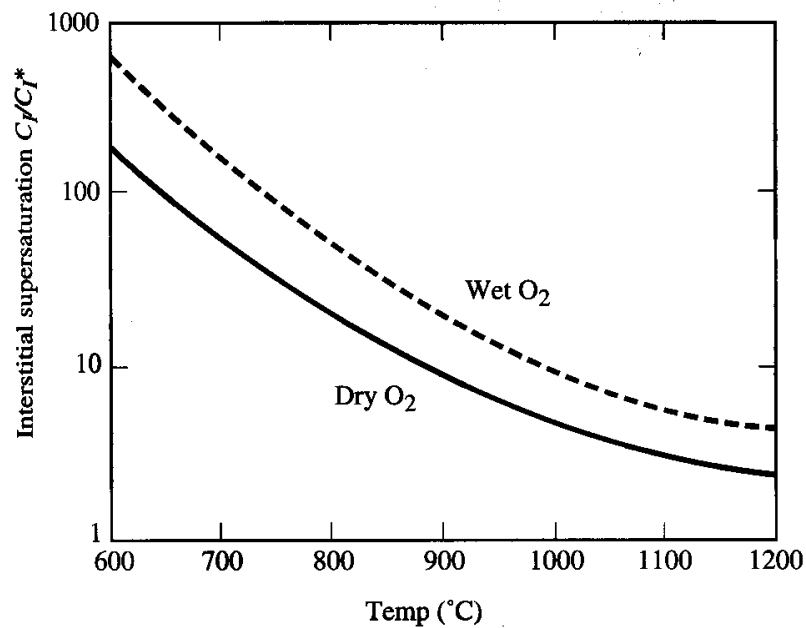 • **Sb : Oxidation-retarded diffusion (ORD)**

- **Perturbed point-defect concentrations caused by the surface oxidation**

- **Growth of oxidation stacking faults** ü
             ý same underlying phenomena
  OED   þ

- **Stacking faults = nonequilibrium defect structures composed of an extra partial plane of interstitilas**
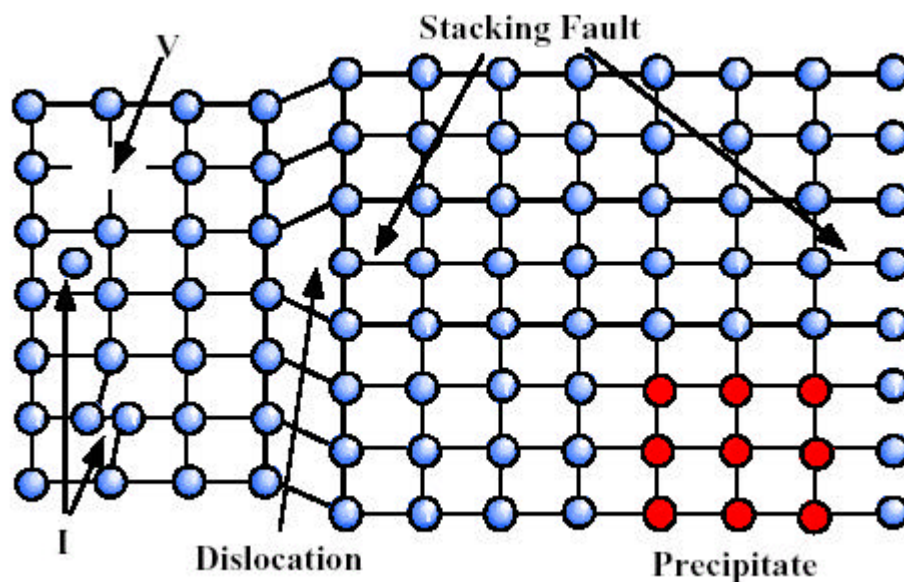
- **When Si is oxidized ?   expansion of 30% ?   compressive stress ?   injection of interstitial to make space at the Si surface**

    large size
- **Sb prefers to diffuse with vacancies. The intertitials recombine with vacancies ?   vacancy concentration? ?   D?**

- **The interstitial level depends on the balance between G and R**

$$C_I \; a \; \sqrt{\dfrac{dx}{dt}}$$

- **Interstitial supersaturation is larger at lower oxidation T**
  ? enhancement in D

7.5.9 Dopant Diffusion Occurs by Both I and V
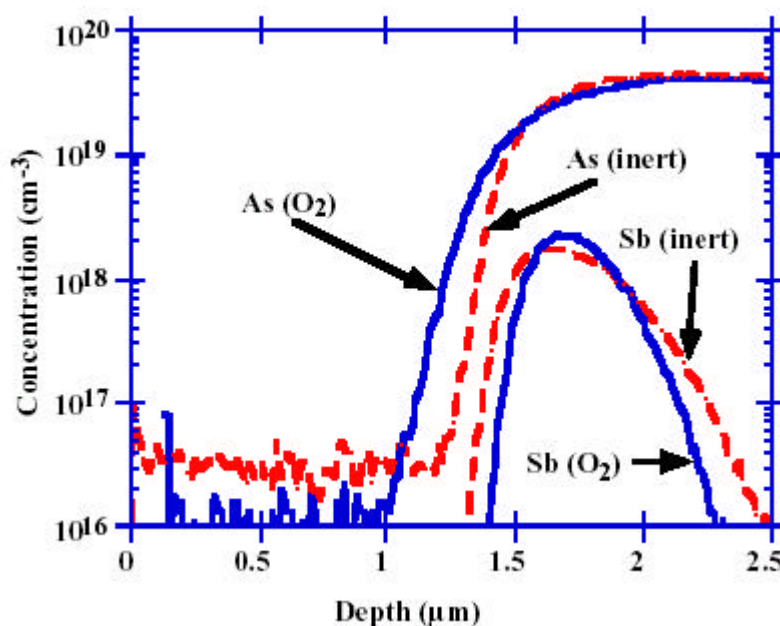
- **The diffusion of** ⎡ **As is enhanced**
  ⎣ **Sb is retarded**
- **Nitridation of the silicon surface in an ammonia has exactly the opposite effects**
  - ⎡ **B & P : retarded diffusion**
  - ⎣ **Sb : enhanced**
- **Nitridation injects vacancies**
- **Dopants diffuse with a fraction f_I interstitial-type diffusion and with a fraction $f_V = 1 - f_I$ vacancy-type mechanism**

$$D_A^{eff} = D_A^* \left(f_I \frac{C_I}{C_I^*} + f_V \frac{C_V}{C_V^*} \right)$$

$$\left(\frac{D}{D^*} \right)^R = f_I^R \frac{C_I}{C_I^*} + f_V^R \frac{C_V}{C_V^*}$$

$$= (1 - f_V^R) \frac{C_I}{C_I^*} + f_V^R \frac{C_V}{C_V^*}$$

- **A very conservative assumption :** $\left(\dfrac{D}{D^*} \right)^R \geq (1 - f_V^R) \dfrac{C_I}{C_I^*}$

  An even more conservative assumption : $f_V^R > 1 - \left(\dfrac{D}{D^*} \right)^R$
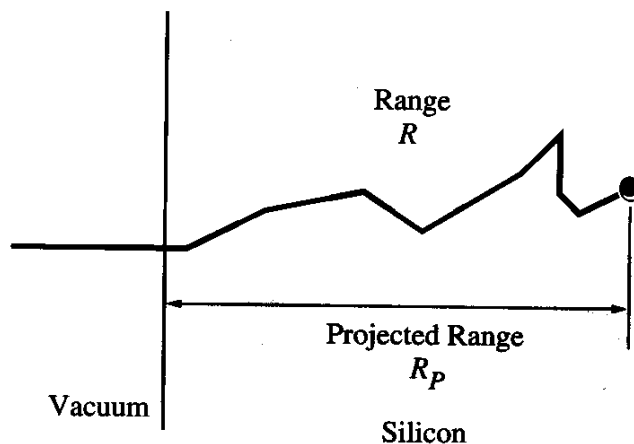
Chap 8 Ion Implantation

8.1 Introduction
- **Create a cascade of damage that may displace a thousand silicon atoms for each implanted ion**

8.2 Historical Development and Basic Concepts
- **Provides a very precise means to introduce a specific dose (the electrical charge on the ion allows them to be counted by collection in a Faraday cup)**
- **I/I is a random process**

- **Large numbers of ions are implanted so an average depth for the implanted dopants can be calculated**
- **Heavy ions do not travel as far as light ions**