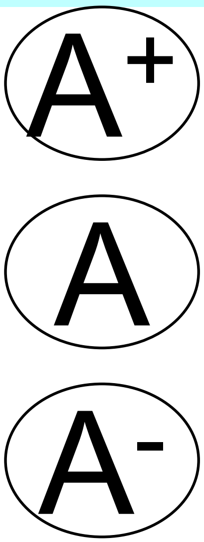
1) Implant Profile depends only on incident ion momentum, NOT on charge state



Same momentum ⇒ Same implant profile

Note : Kinetic Energy = $(\text{momentum})^2 / 2M$

2) Charge carried by ions will be neutralized by charges in the substrate after implantation.

3) n, p, Nd+, Na- charges in semiconductors are caused by the chemistry of the implanted dopants, and are NOT related to charges carried by the ions.

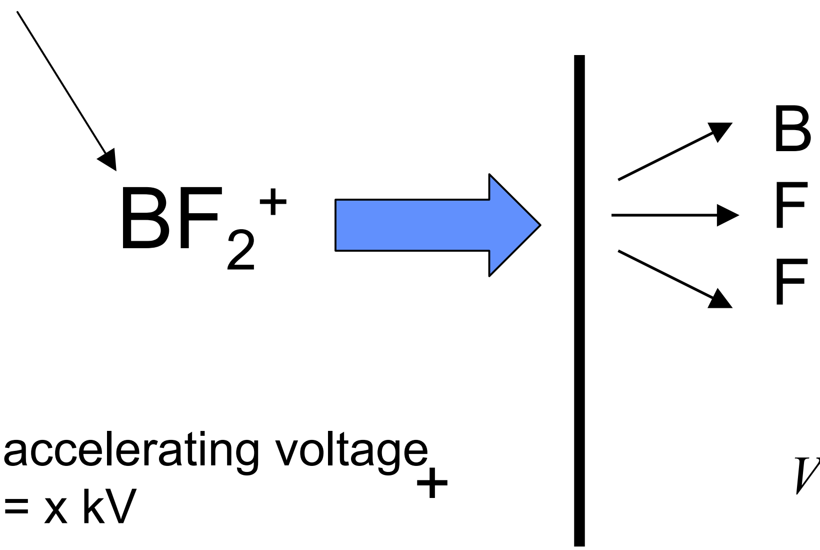
Kinetic Energy of Multiple Charged Ions

accelerating voltage = x kV

Singly charged	B^+, P^+, As^+	→	Kinetic Energy = x · keV
Doubly charged	B^{++}	→	Kinetic Energy = 2x · keV
Triply charged	B^{+++}	→	Kinetic Energy = 3x · keV

Molecular Ion Implantation

Kinetic Energy = x keV



- accelerating voltage = x kV +

Solid Surface

Molecular ion will dissociate immediately into atomic components after entering a solid. *All atomic components will have same velocity after dissociation*.

B has 11 amu
F has 19 amu

$$Velocity \quad v_B = v_F = v_F$$

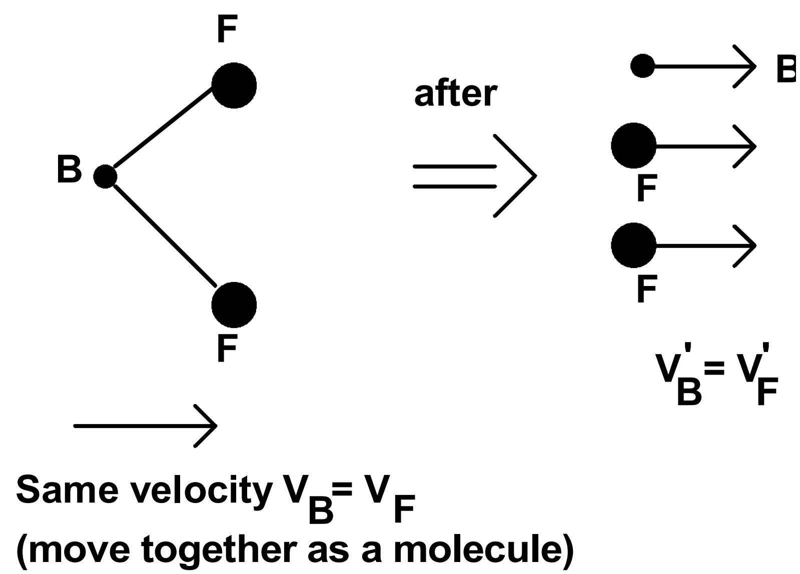
$$K.E.of\ B = \frac{1}{2} m_B \cdot v_B^{2}$$

$$K.E.of\ F = \frac{1}{2} m_F \cdot v_B^{2}$$

$$\frac{K.E.of\ B}{K.E.of\ BF_2^{+}} \approx \frac{11}{11+19+19} = 20\%$$

All Atomic Components have same Velocity…

Binding energy of molecule (~ several eV) is **negligible** compared with implantation energy (many keV).



$$\frac{1}{2}m_B v_B^2 + 2(\frac{1}{2}m_F v_F^2) = \frac{1}{2}m_B v'_B{}^2 + 2(\frac{1}{2}m_F v'_F{}^2) \qquad [1]$$

$$(m_B + 2m_F)v_B = m_B v'_B + 2m_F v'_F \qquad [2]$$

The only way to satisfy both [1] and [2] is :

$v'_B = v'_F = v_B = v_F$.

Molecular Implantation for Shallow Junctions

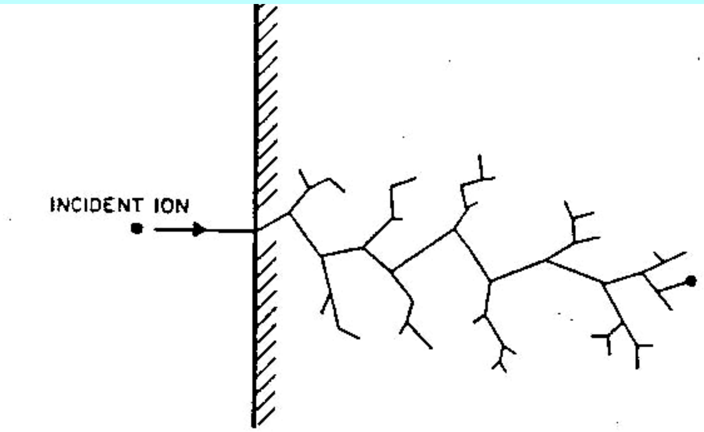
For conventional beamline implanters
Beam current I ↓ as accelerator voltage ↓

B^+ I (B^+) ↓ as voltage < 5kV

BF_2^+ I (BF_2^+) can still be high with 25kV accelerating voltage but the effective B implantation energy is ~5 keV

** For ultra-shallow junction which needs ~1keV B+ energy, $B_{10}H_{14}$(+) at ~10keV is proposed*

Implantation Damage



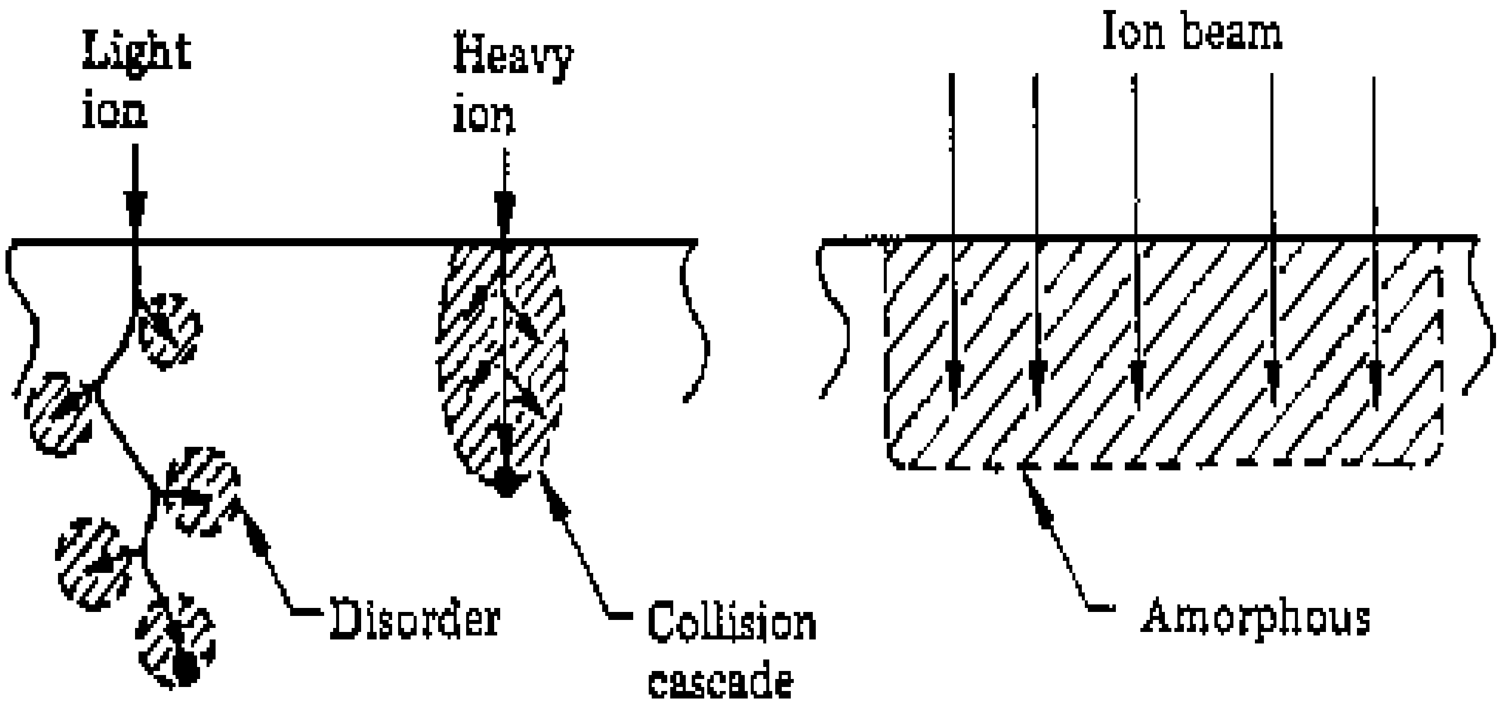
After implantation, we need an annealing step.
A typical ~900^{o}C, 30min will:

(1) Restore Si crystallinity.

(2) Put dopants into Si substitutional sites
for electrical activation

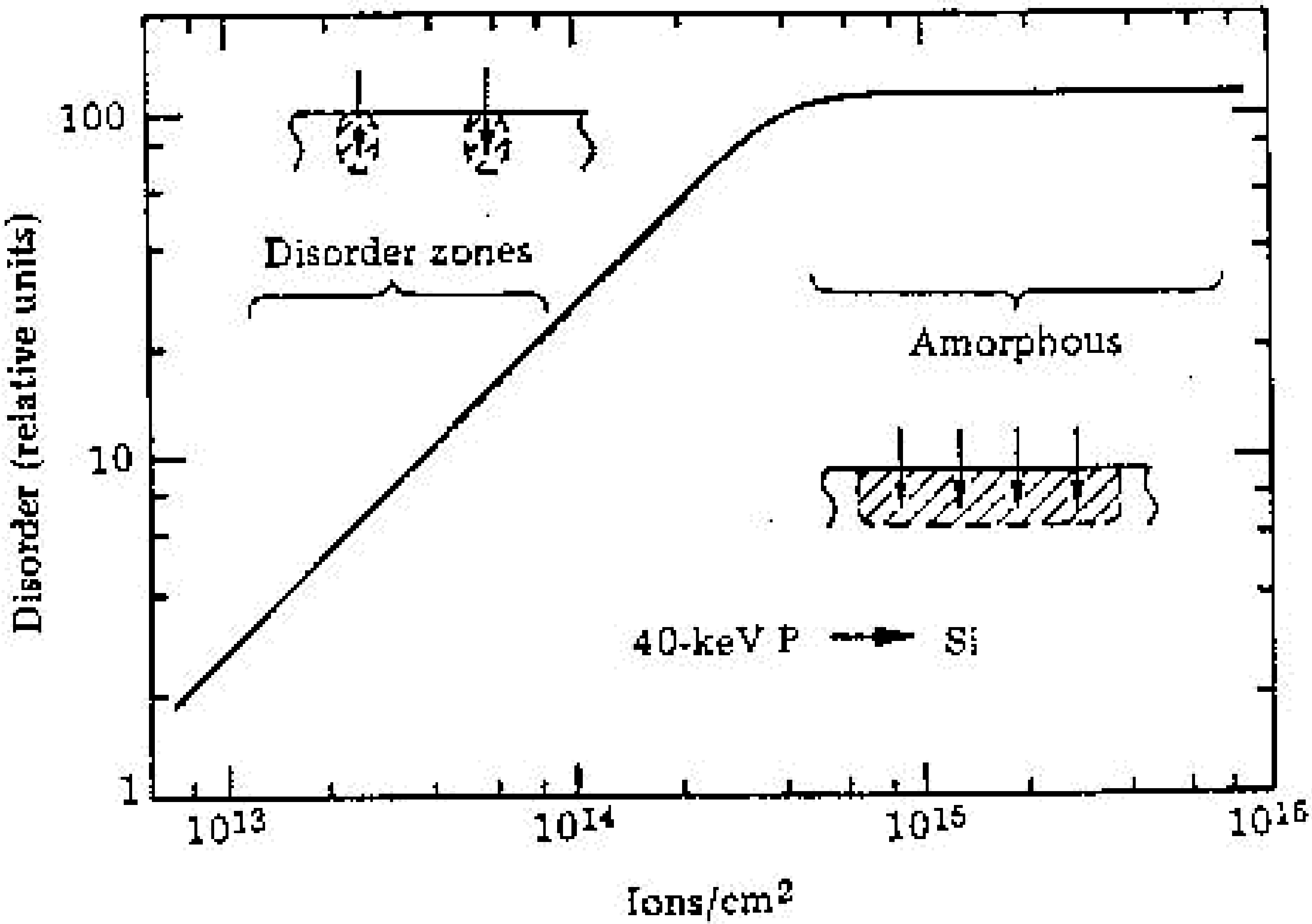
Implantation Damage

•

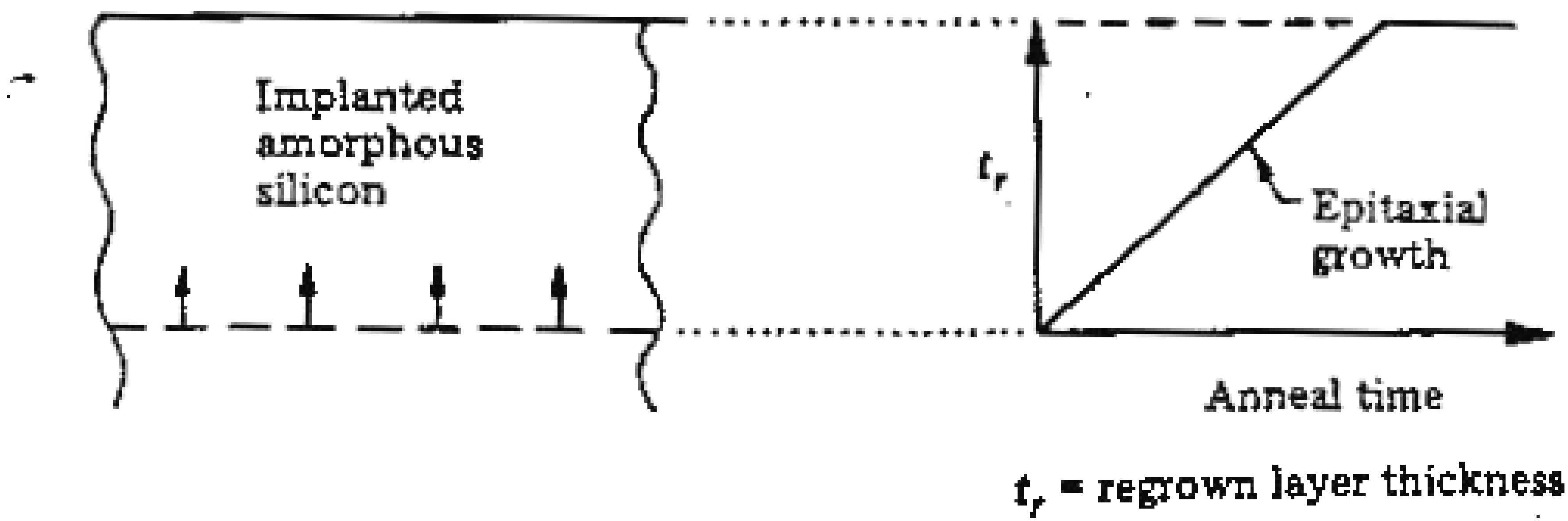


Schematic of the disorder produced along the individual paths of light and heavy ions and the formation of an amorphous region.

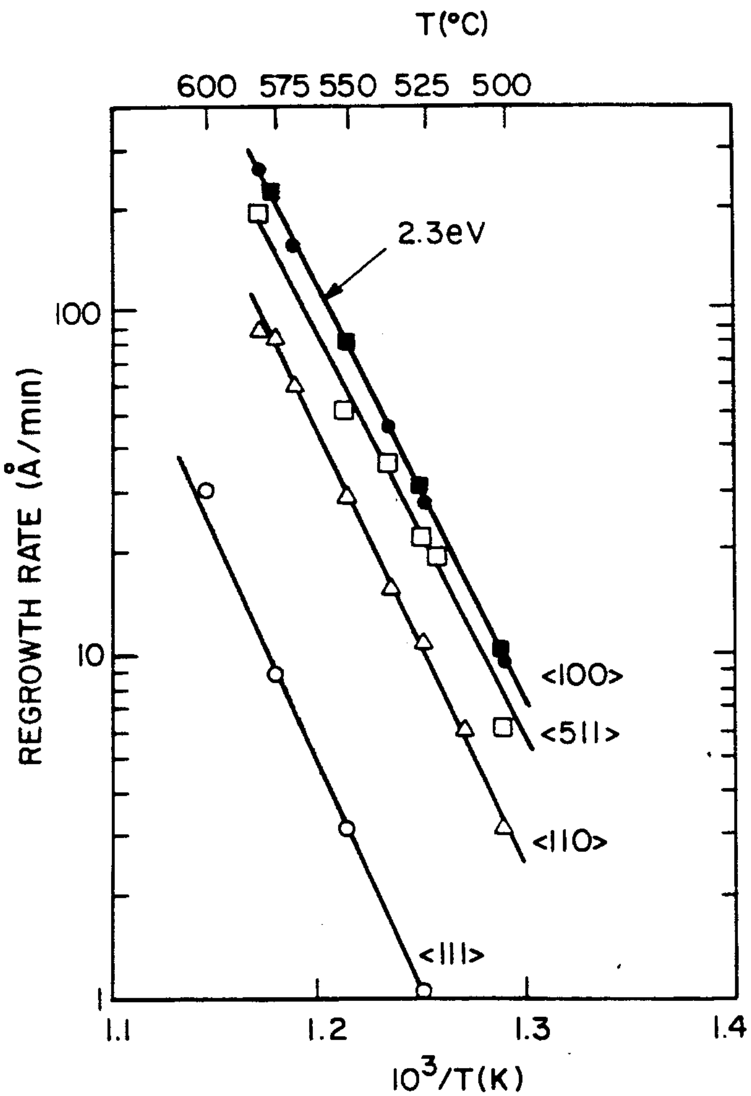
Amount and type of Crystalline Damage



Solid Epitaxial "Growth" through the Implant Damaged Region



Solid Epitaxial "Growth" through the Implant Damaged Region – cont.



(1) Regrow the amorphous region at T = 500-600°C into single crystal. The substrate acts as a seed. If higher temperatures are used then nucleation within the amorphous layer takes place making it polycrystalline and crystal structure can never be regained. This temperature range also recovers most of the electrical activity.

(2) A further anneal at T>900°C restores the crystal structure and electrical activity 100%.

Dopant Activation Versus Annealing Temp

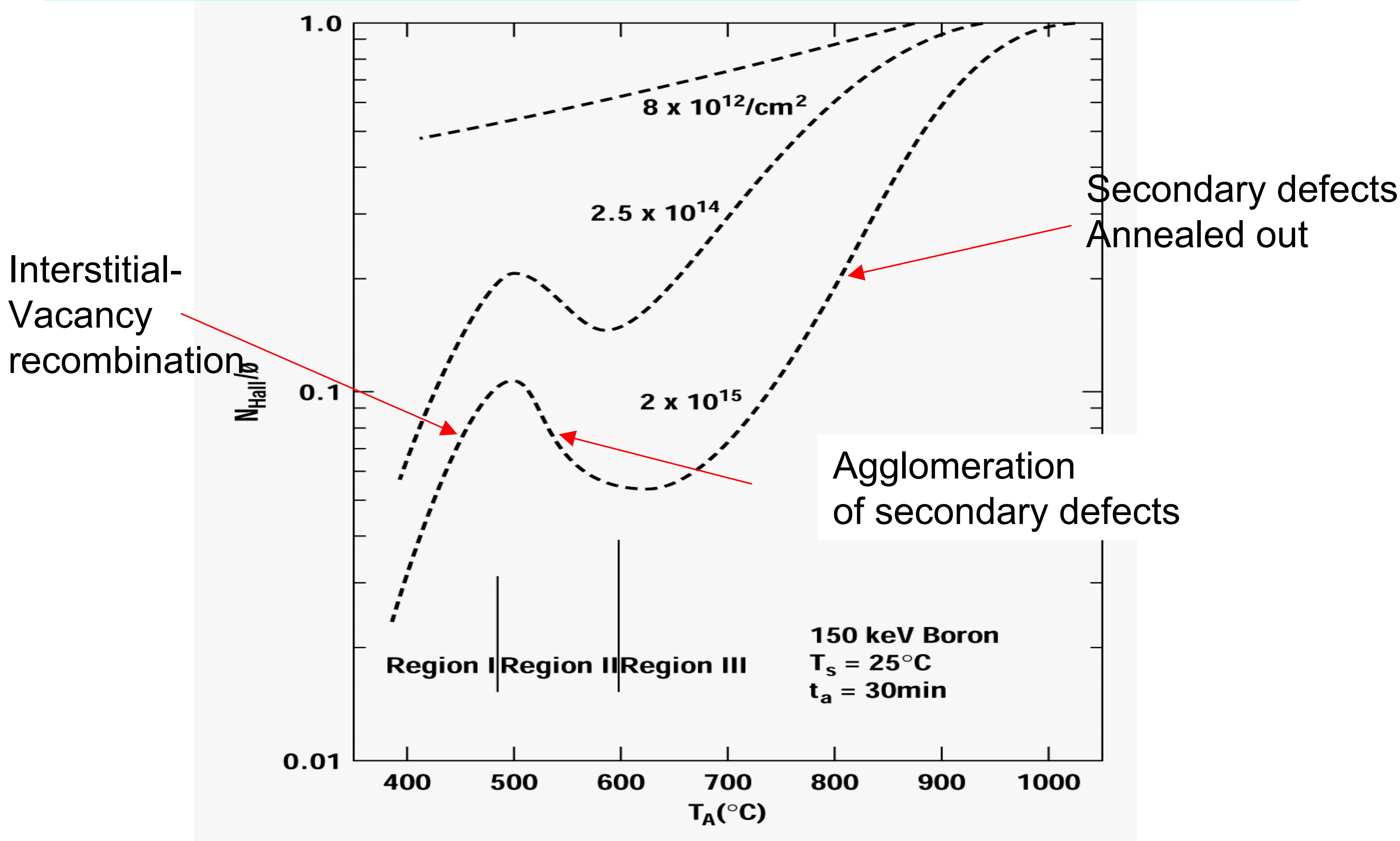
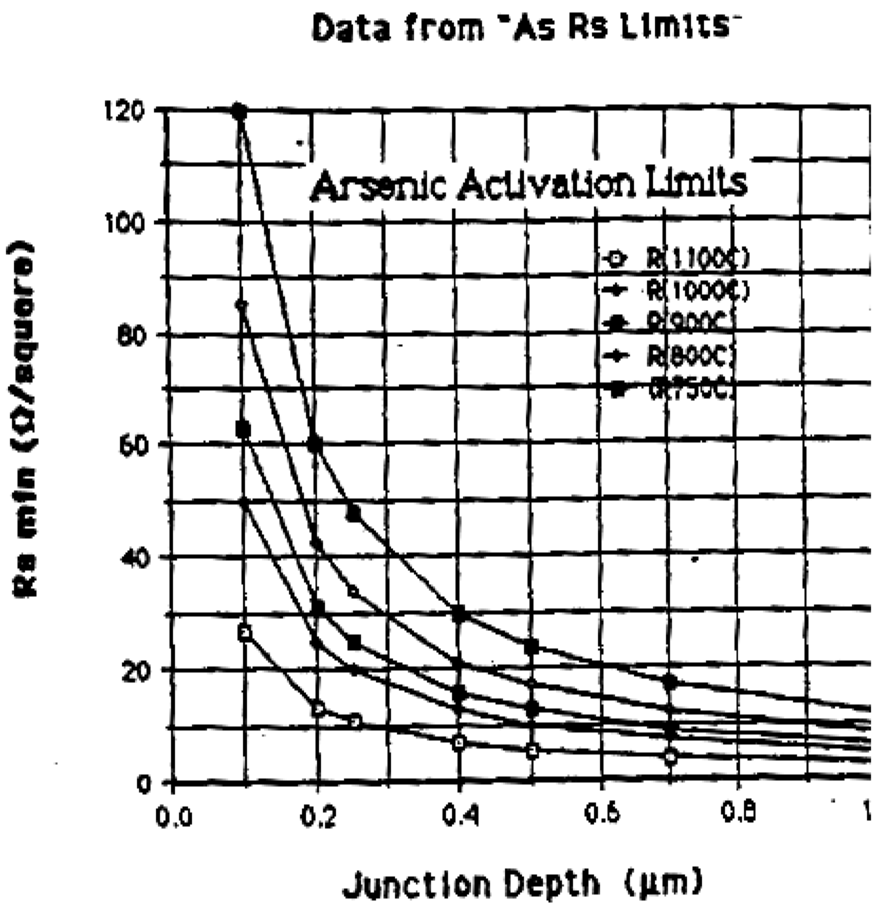
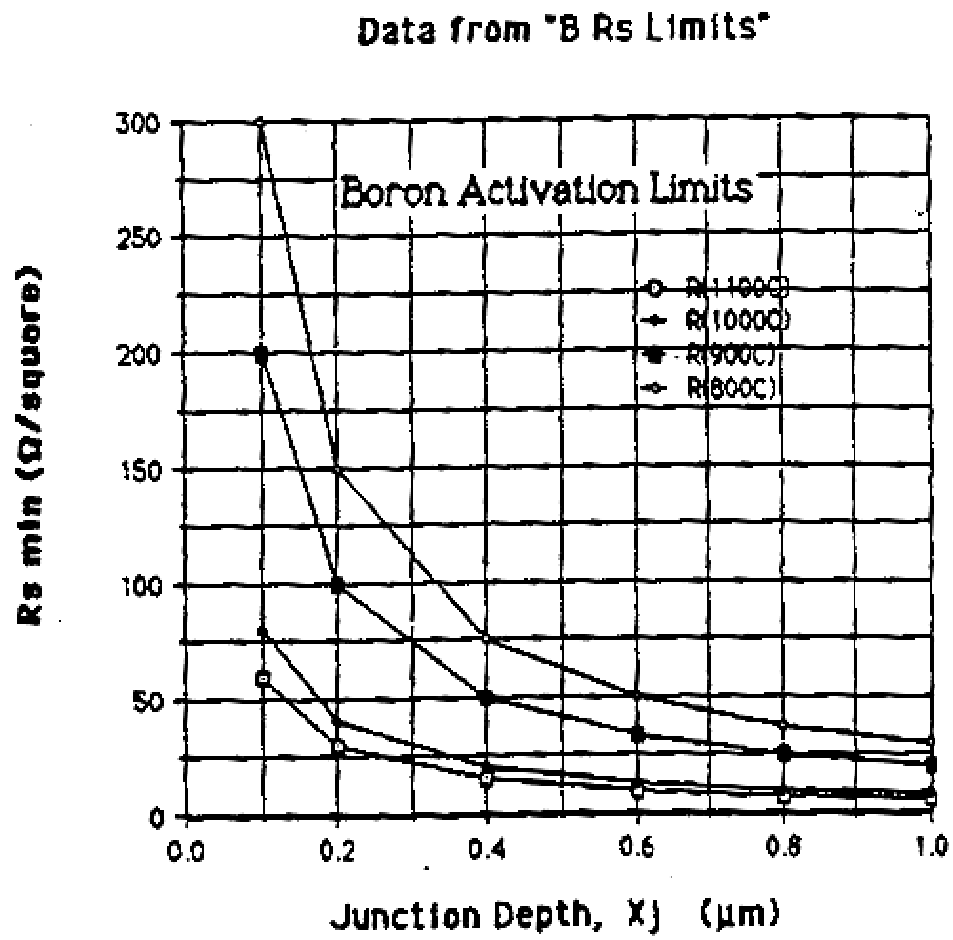


Figure 5.15 Fraction of implanted boron activated in silicon for several isochronal anneals *(after Seidel and MacRae, reprinted by permission, Elsevier Science).*

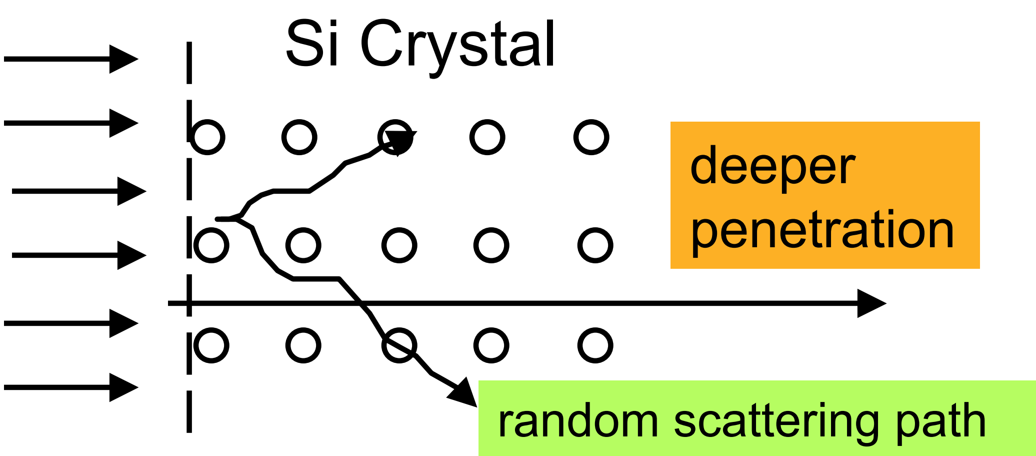
Dopant Activation

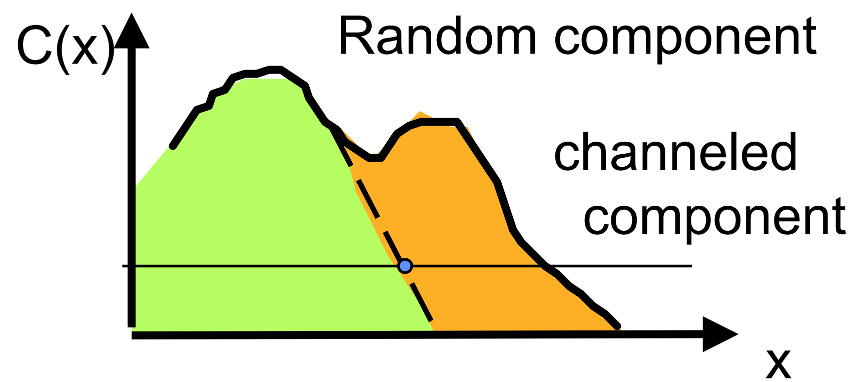
* Sheet Resistance is limited by dopant solid solubility
* Shallower junctions will have higher R_S

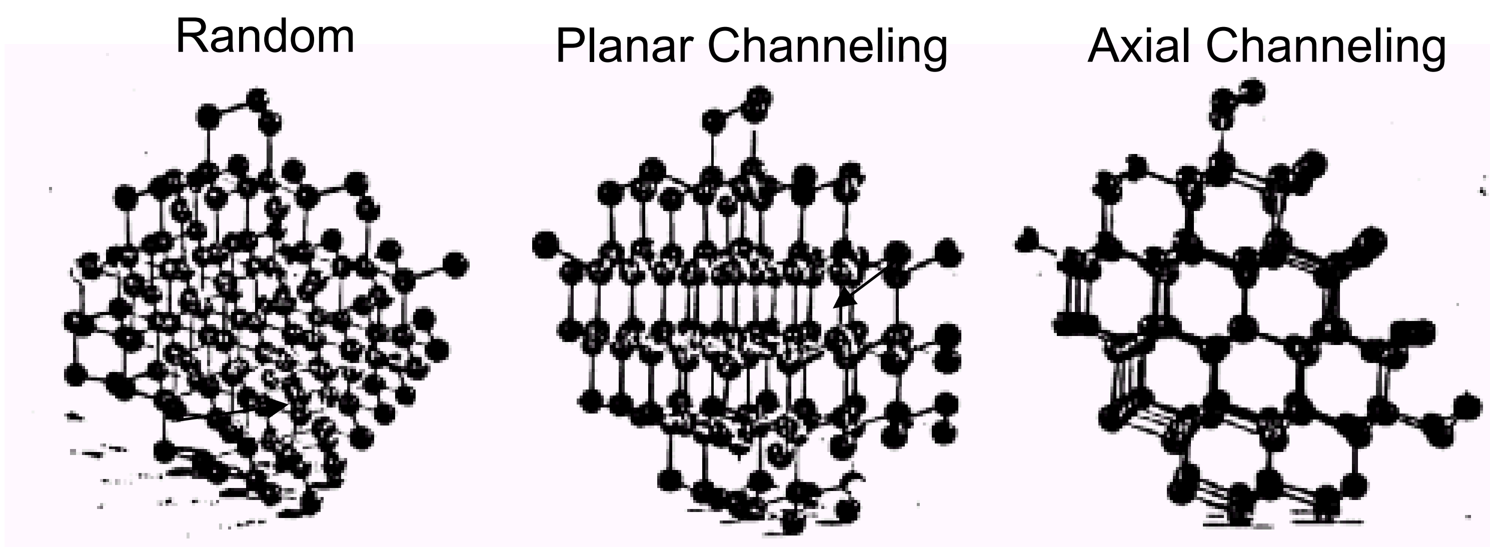




Ion Channeling

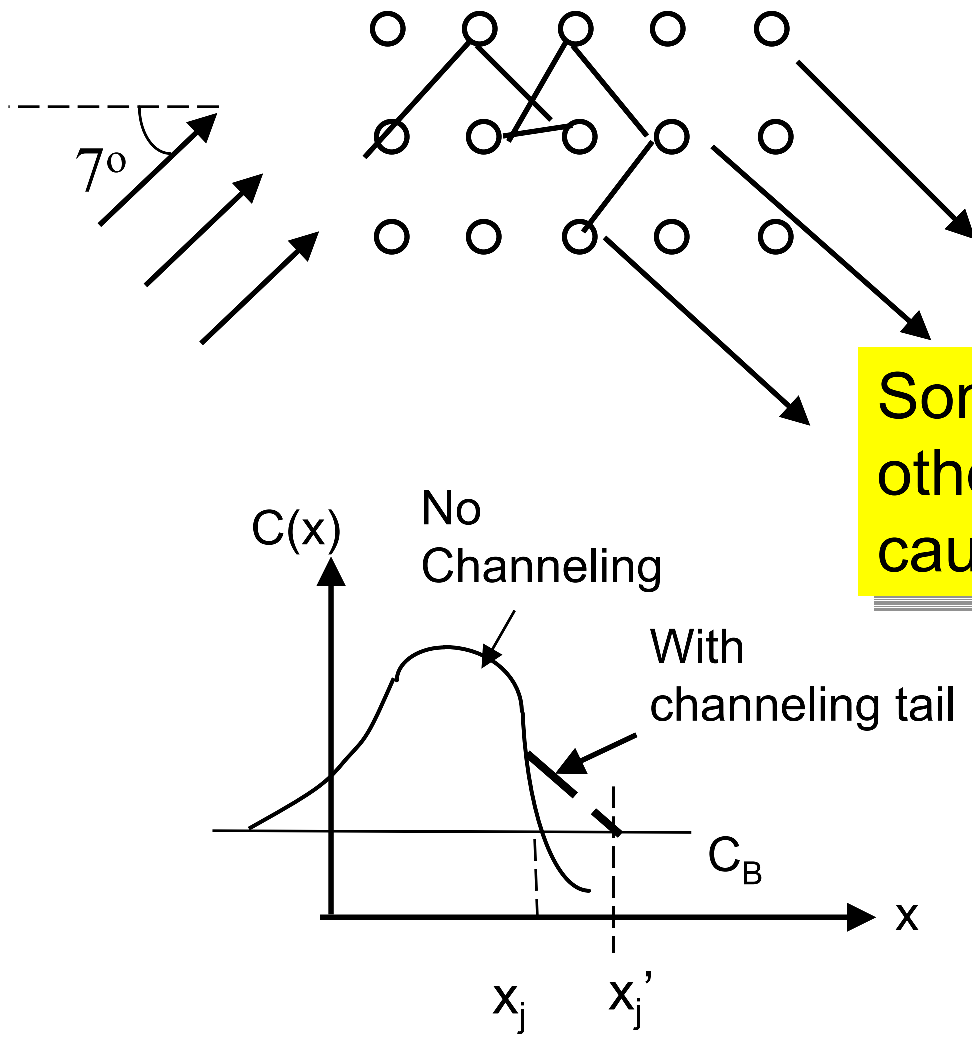






To minimize channeling, we tilt wafer by 7° with respect to ion beam.

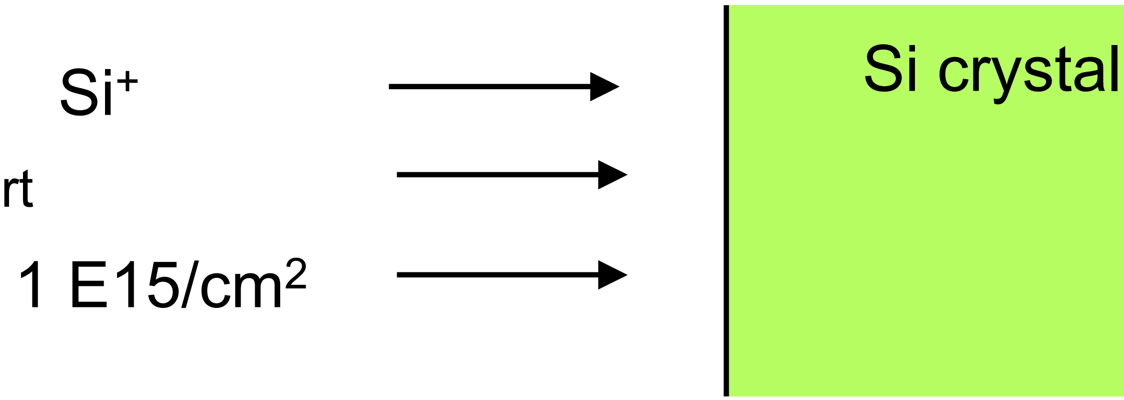
"Lucky Ions"



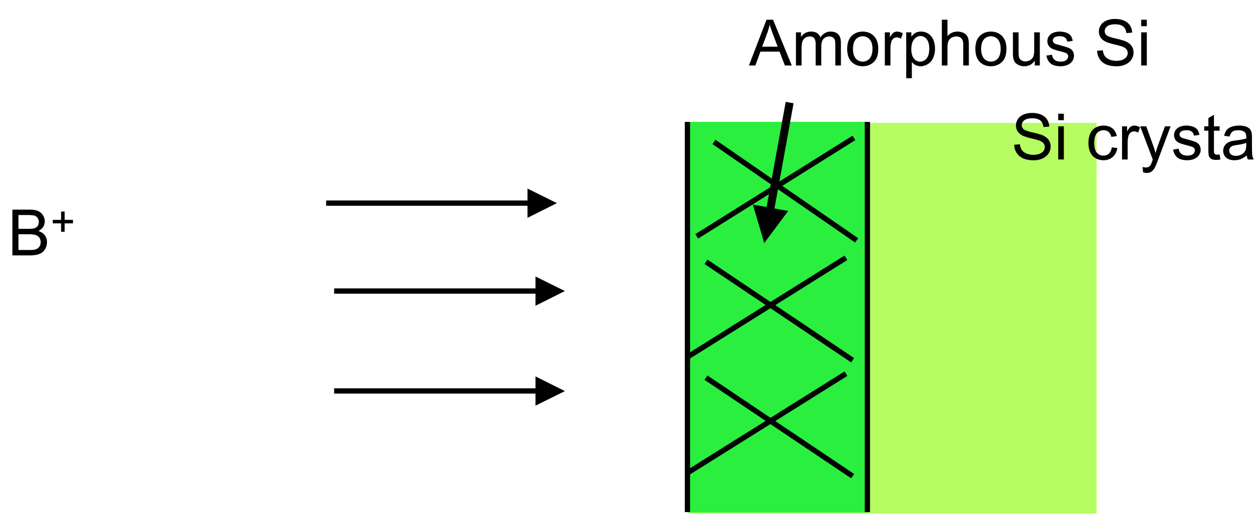
Some scattered ions fall into other channeling directions, causing deeper penetration

Prevention of Channeling by Pre-amorphization

Step 1
High dose Si+ implantation to covert surface layer into amorphous Si



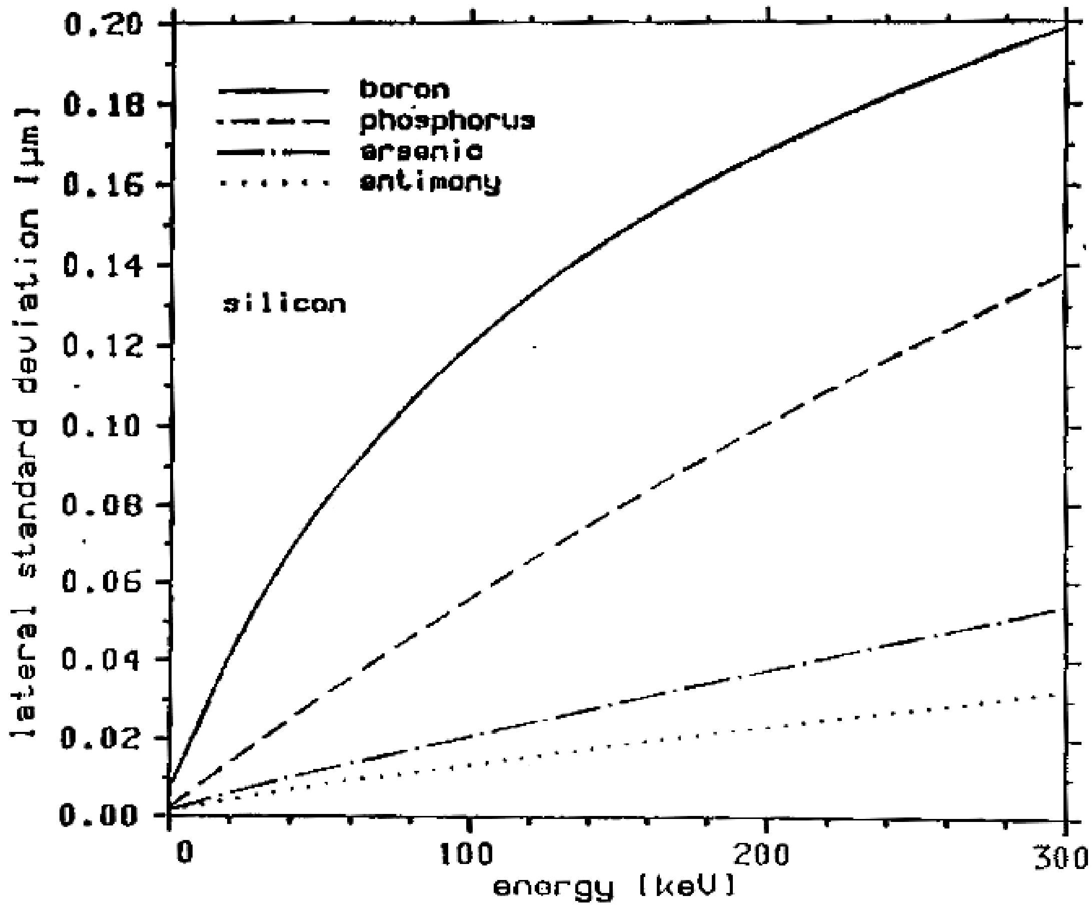
Step 2
Implantation of desired dopant into amorphous surface layer



Disadvantage : Needs an additional high-dose implantation step

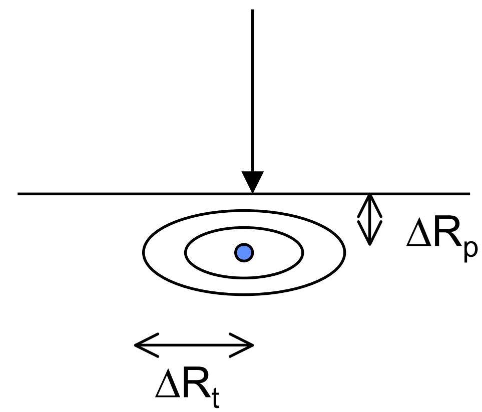
Transverse (or Lateral) Straggle (ΔR_t or $\Delta R_\perp$)

ΔR_t

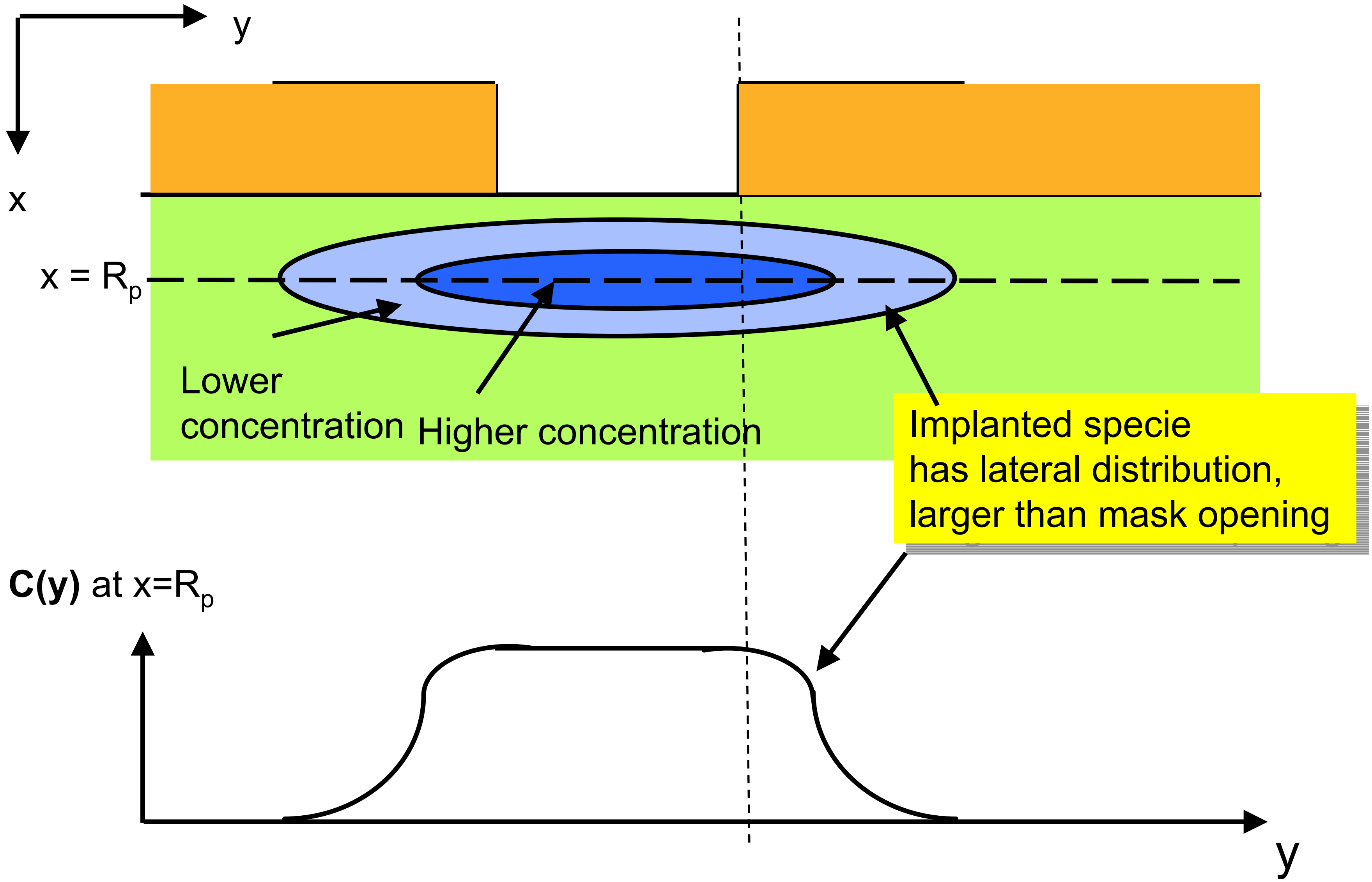


Lateral standard deviation of boron, phosphorus, arsenic and antimony in silicon

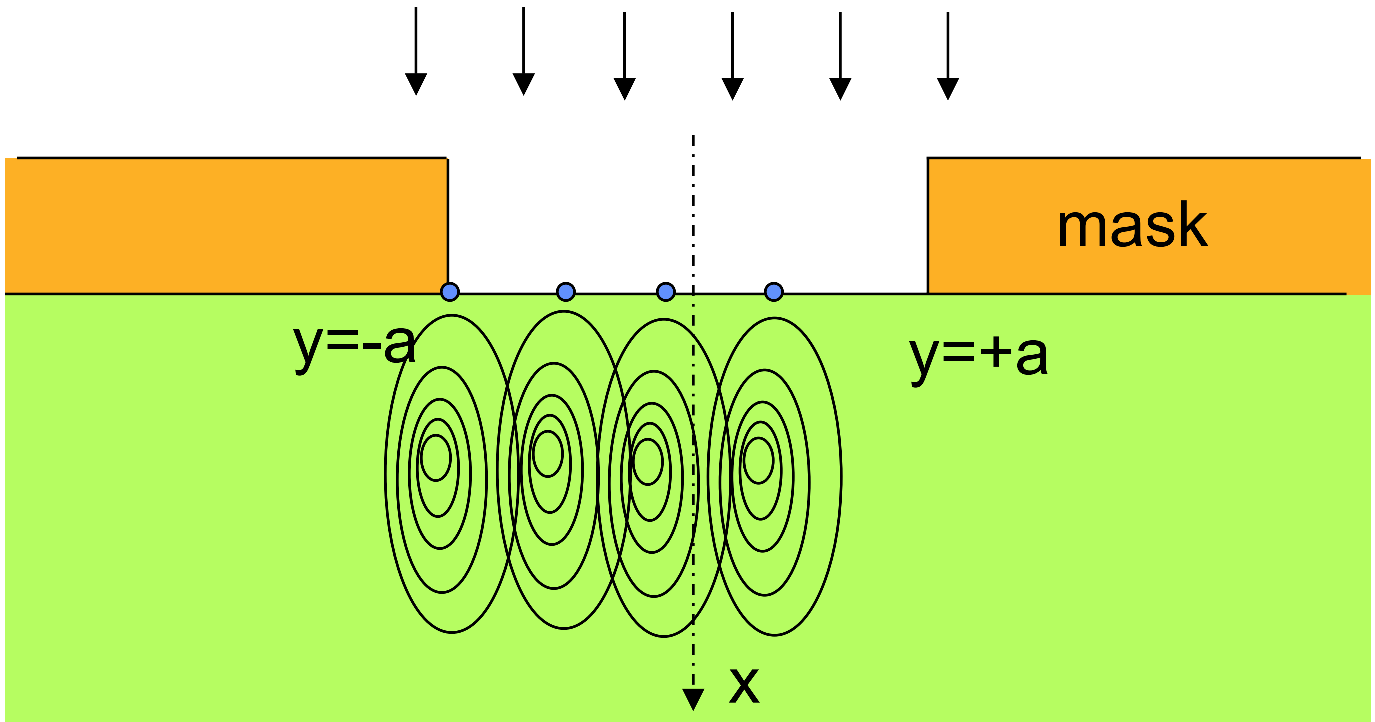
$$\frac{\Delta R_t}{\Delta R_p} > 1$$



Lateral Scattering Causes Feature Enlargement



A 2-D formulation of Implantation Profile



$$C(x,y) = K \cdot C(x) \cdot \int_{-a}^{+a} e^{\frac{-(y-y')^2}{2(\Delta R_t)^2}} dy$$

$$= K \cdot C(x) \cdot \left[erfc\left(\frac{y-a}{\sqrt{2}\Delta R_t}\right) - erfc\left(\frac{y+a}{\sqrt{2}\Delta R_t}\right) \right]$$

A 2-D formulation of Implantaion Profile – cont.

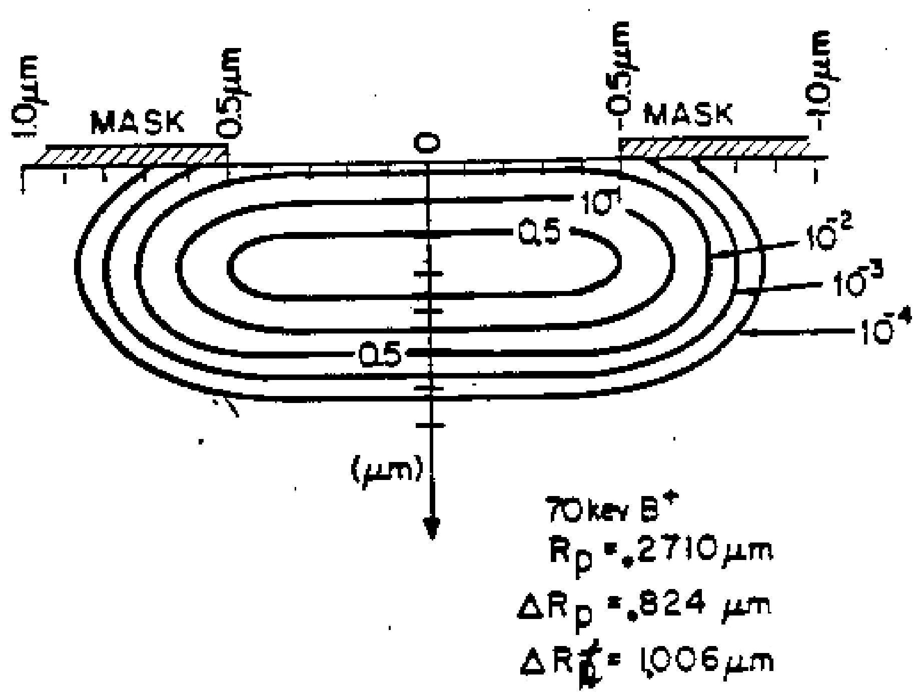
For $a \rightarrow \infty$ (i.e. no mask)

$$C(x, y) = C(x)$$

$$\therefore C(x, y) = C(x) \cdot K \cdot [\mathrm{erfc}(-\infty) - \mathrm{erfc}(+\infty)]$$

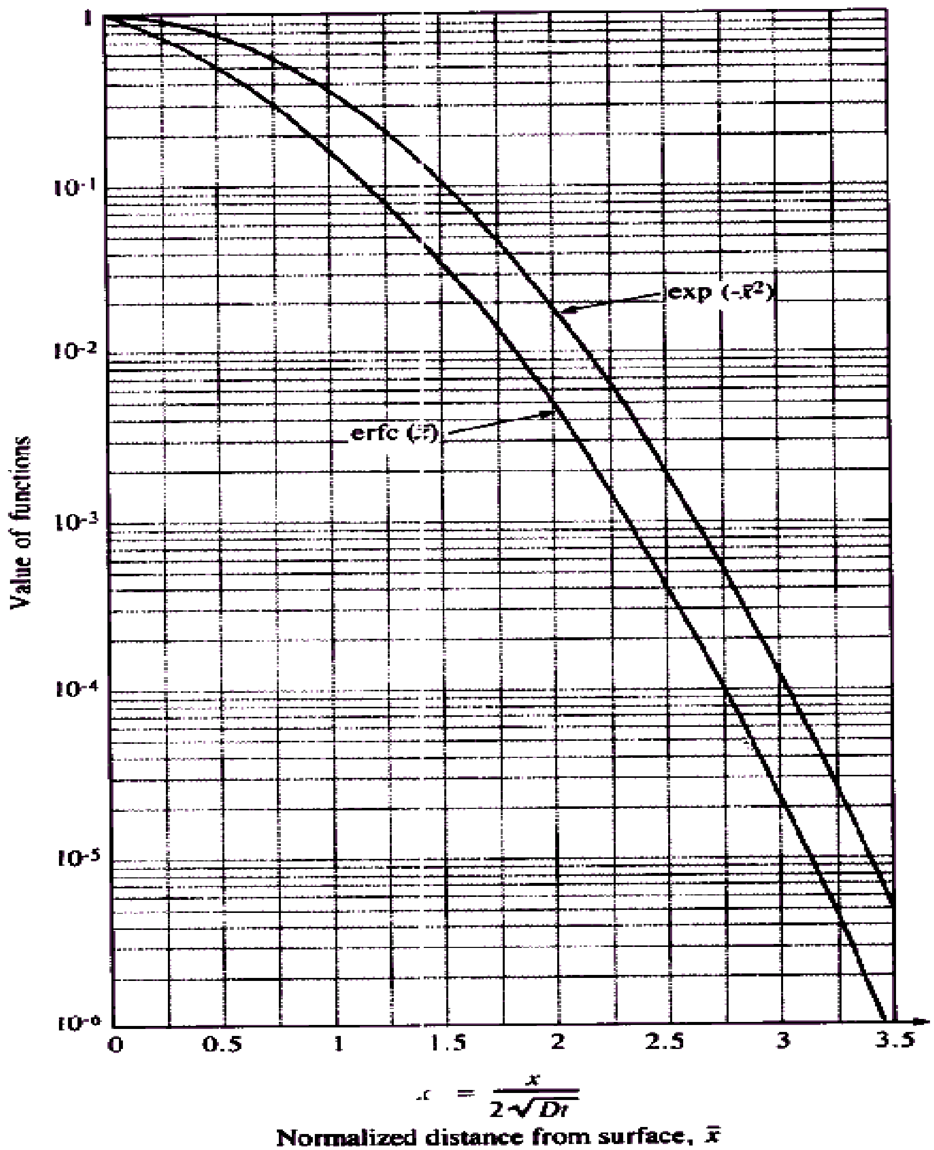
$$C(x) = C(x) \cdot K \cdot 2$$

$$\therefore K = \frac{1}{2}$$



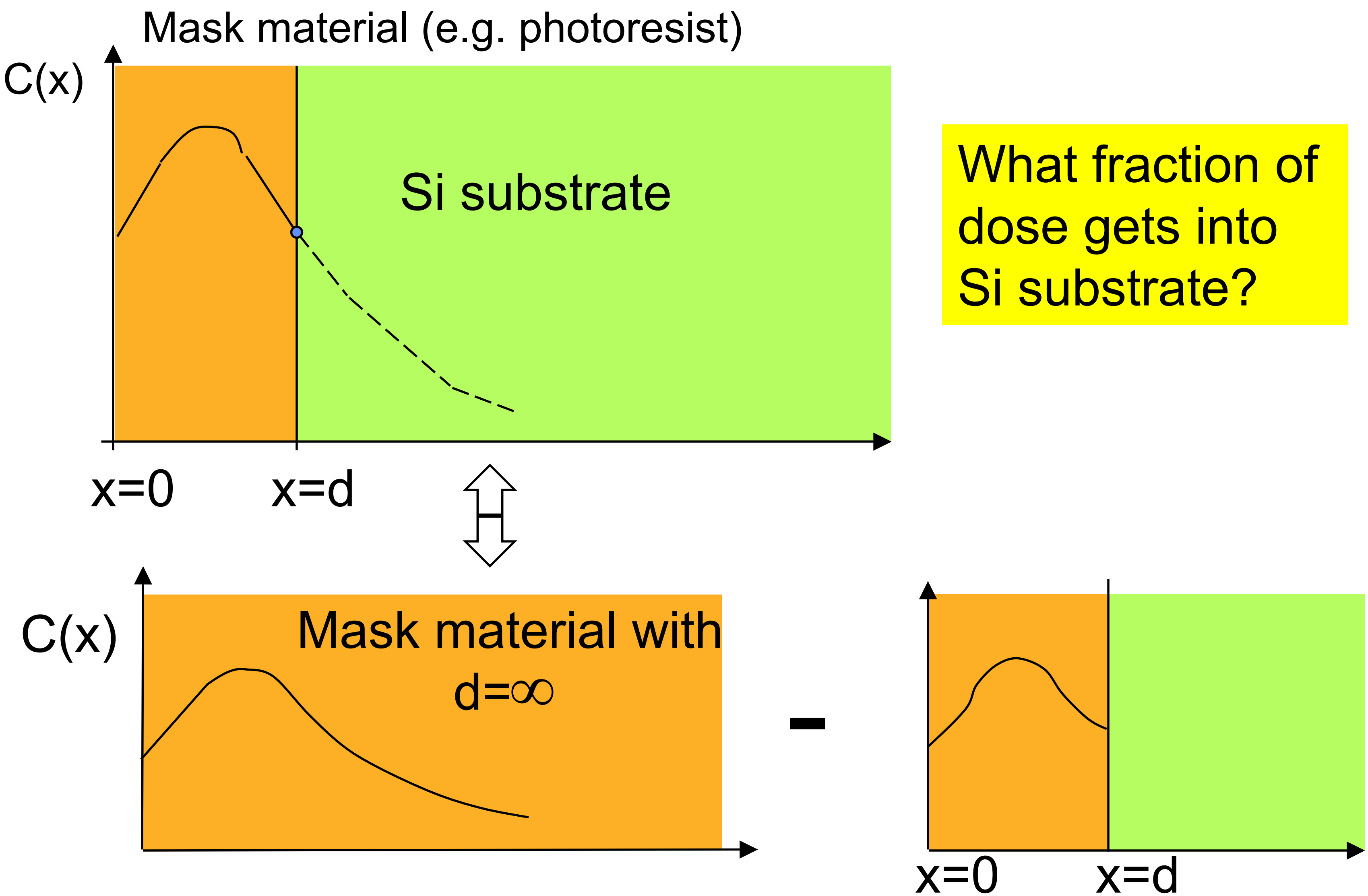
Semi-log Plots of Gaussian and erfc functions

(details of erfc function also covered in Diffusion section of EE143 Reader)



[Curves also given in Jaeger]

Transmission Factor of Implantation Mask



What fraction of dose gets into Si substrate?

Transmitted Fraction

$$T = \int_0^\infty C(x)dx - \int_0^d C(x)dx$$

$$= \frac{1}{2} erfc\left\{\frac{d - R_p}{\sqrt{2}\Delta R_p}\right\}$$

R_p, ΔR_p are values of for ions into the **masking material**

$$erfc(x) = 1 - \frac{2}{\sqrt{\pi}} \int_0^x e^{-y^2} dy$$

Rule of thumb : Good masking thickness

$$d = R_p + 4.3\Delta R_p \qquad \frac{C(x=d)}{C(x=R_p)} \sim 10^{-4}$$