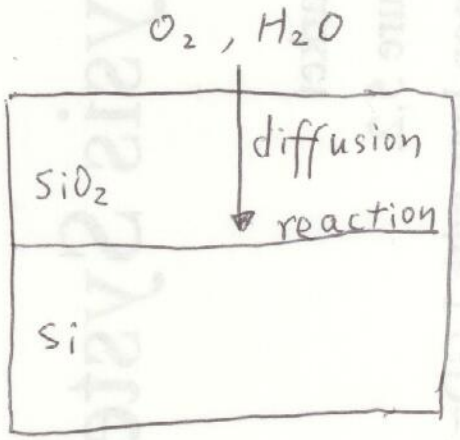
#17

Processing (continued)

The choice of the (100) surface

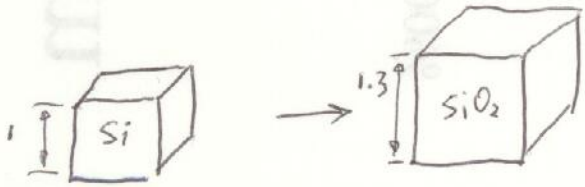
- The (100) surface has the lowest Si atom density; the (111) has the highest
  [Therefore (100) oxidizes the slowest.]
- The Si(100)/SiO_2 interface has the lowest surface state density (defects associated w/ dangling bonds).
- Historically, (111) was used for bipolar technologies, due to relative ease of growth.

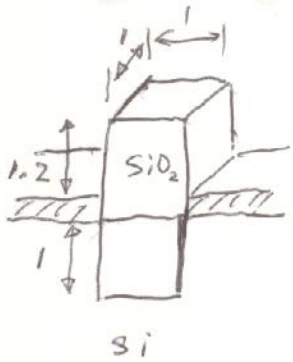
Si oxidation – the big picture



$$Si + O_2 \longrightarrow SiO_2$$

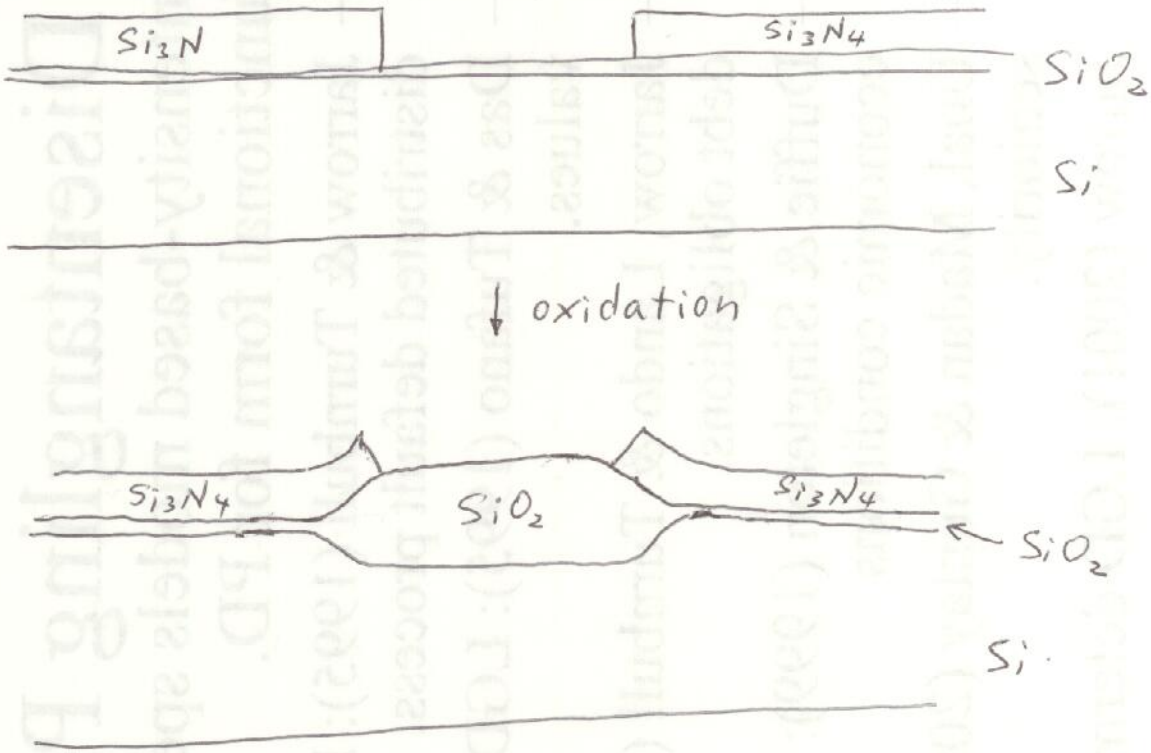
$$Si + 2H_2O \longrightarrow SiO_2 + 2H_2$$



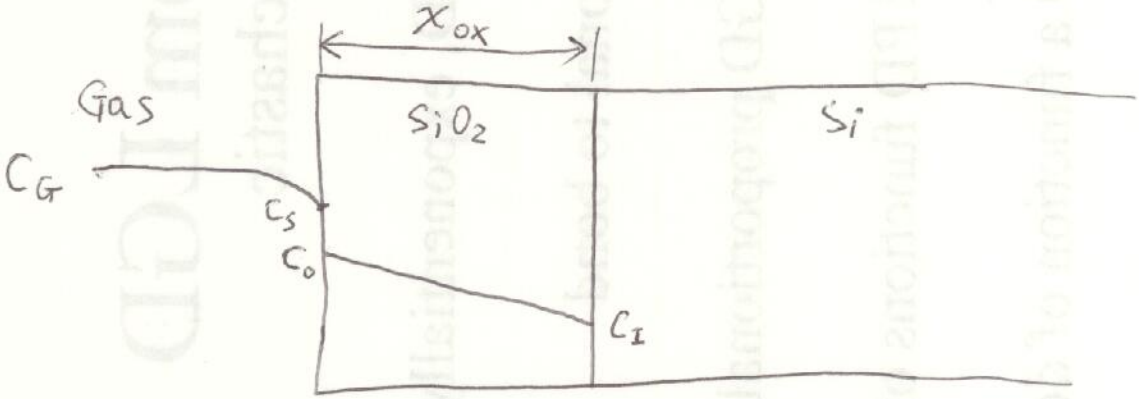


$1.3^2 \approx 2.2$

Active region and field formation



Oxidation Kinetics



$\vec{F_1}$ $\vec{F_2}$ $\vec{F_3} = k_s C_I$

$$F_1 = F_2 = F_3$$

Introduce two parameters A & B (T-denpedent)

$$x_{ox} = \frac{A}{2}\left[\sqrt{1+\frac{t+\tau}{A^2/4B}} - 1\right]$$

t : time

τ : If $x_{ox}(0) \equiv x_i \neq 0$, τ is the time to generate x_i under the same conditions (as if the process started τ earlier)

$$\tau = \frac{x_i^2 + A x_i}{B}$$

- What are the dimensions (units) of A & B?

$x_{ox} = x_{ox}(t+\tau)$ is linear-parabolic

For small $t+\tau$ (i.e. initial stage,

$\frac{t+\tau}{A^2/4B} \ll 1$).

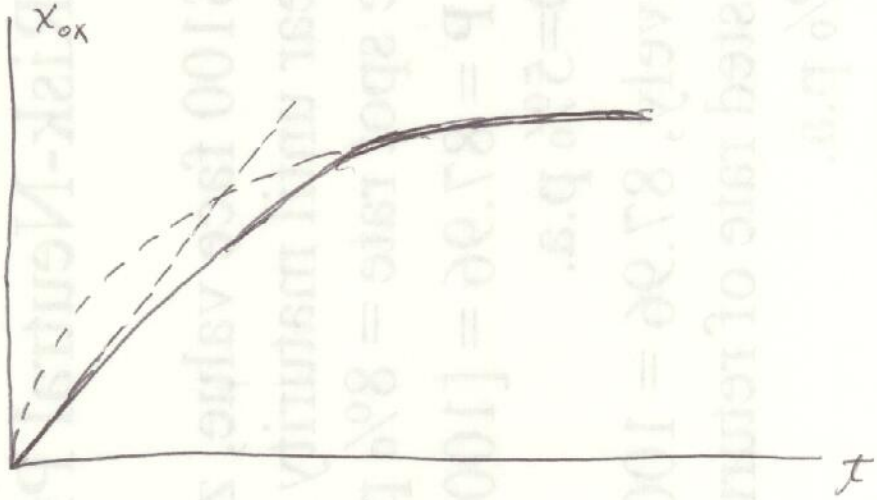
$x_{ox} \cong \frac{B}{A}(t+\tau)$. — linear

How to get to this approximation?

For large $t+\tau$,

$$x_{ox} = \sqrt{B(t+\tau)} \quad \text{— parabolic}$$

Example: $\tau = 0$



Introducing dopants to Si

— Ion implantation & dopant diffusion

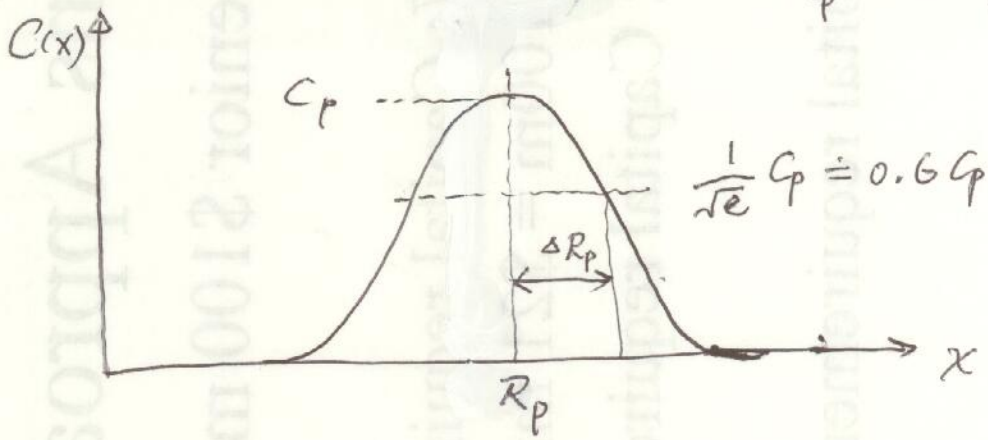
Ion implantation

Precise control of dose & energy
(by I & V of the beam)

But, where the ion ends up is random

$$C(x) = C_p e^{-\frac{(x-R_p)^2}{2\Delta R_p^2}}$$

R_p : range



Total dose

$$Q = \int_{-\infty}^{+\infty} C(x)\,dx = \sqrt{2\pi}\,\Delta R_p\, C_p$$

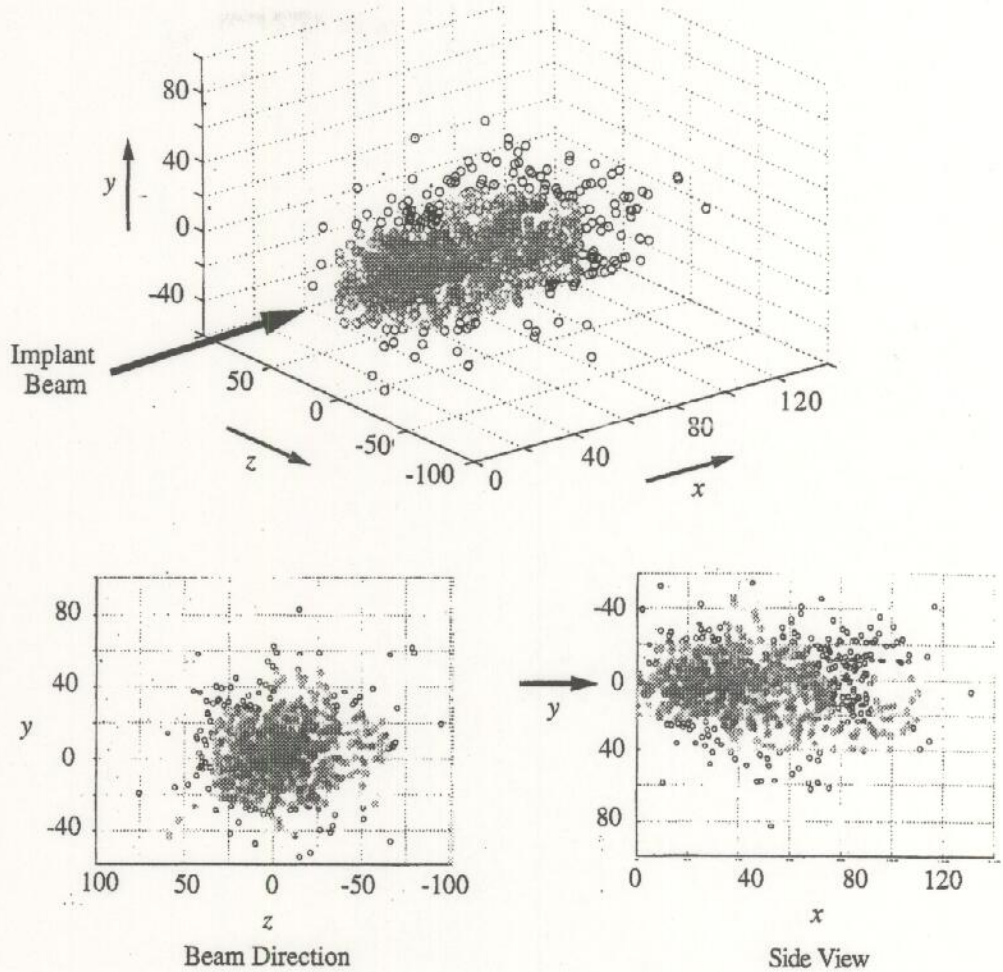


Figure 8–4 Monte Carlo simulations using UT-Marlowe [8.2] of the 3D distribution of 1000 phosphorus ions implanted at 35 keV. The 2D projection (side view) and top view are also shown. The implant beam is centered at $(y,z = 0,0)$ and the axes are in units of nm.

of a MOS transistor, can be dominated by the lateral straggle of the
how far this moves during subsequent annealing. With decreasing dev
the implant straggle under the mask edge is becoming a more impo
modern MOS devices.

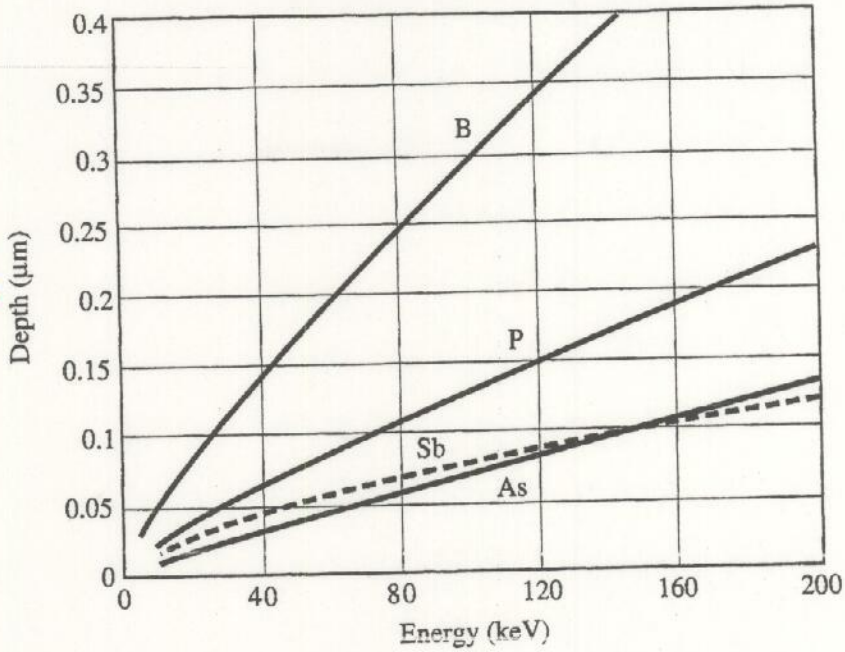
How thick does a masking layer have to be to block the transmission
the mask? The range can be measured in different materials and denser
better masking properties. The range and standard deviation are very s
and silicon dioxide, while a thin layer of metal or a thick photoresist l
ciently mask an implant. In order to act as an efficient mask, the thickn
should be large enough that the tail of the implant profile in the silicon
ified background concentration as illustrated in Figure 8–5. We will use
to identify the ranges and standard deviations in the masking material
in general be different from those in the silicon. Then, the criterion for
ing is that

$$C^*(x_m) = C^* \exp\left(-\frac{(x_m - R_P^*)^2}{\ldots}\right) < C$$

(8.5)

e used as a masking
sk, because implants
e is dominated by the
ns with the Gaussian
uch as under the gate

(range)



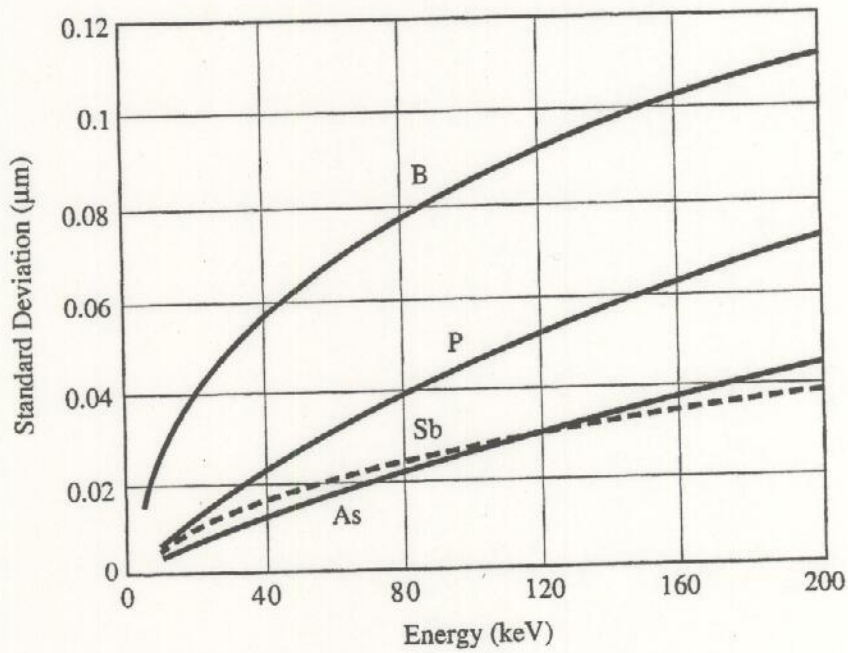


Figure 8–3 Plot of the range R_P (top) and standard deviation ΔR_P (bottom) of common dopants in crystalline silicon tilted and rotated to simulate a random direction. (After [8.1].)

$$C(x,y) = C_{\text{vert}}(x) \exp\left(-\frac{y^2}{2\Delta R_\perp^2}\right)$$

Any layer thick enough to capture the implanted ions can be used as a m
layer. For example, photoresist is often used as a convenient mask, because ir
are performed at room temperature. Near a mask edge, the profile is dominatec
lateral straggle and is given by a sum of point response functions with the G
form of Eq. (8.5). This means that the profile under a mask edge, such as under t

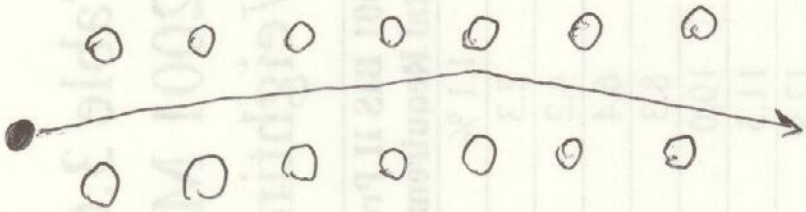
Implatation is a violent process.

Lots of damage is introduced to Si.

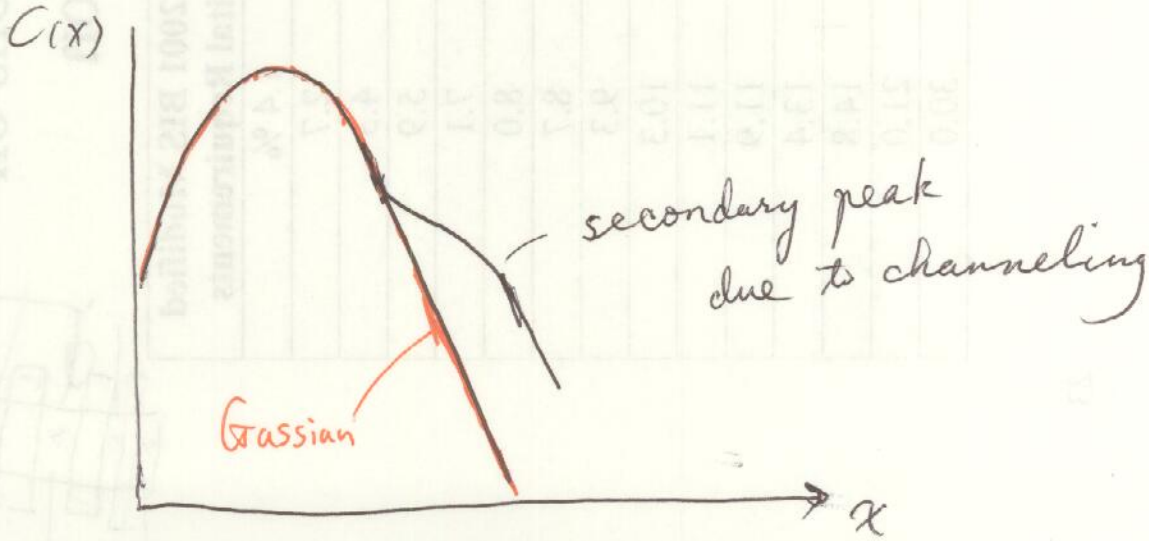
The defects are annealed out during diffusion.

- The defects may significantly impact the diffusion process.

△ Channeling

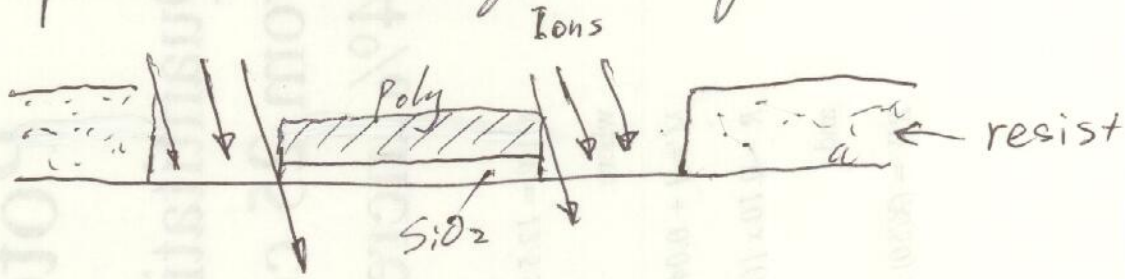


At low incident angles an ion can channel through between crystalline planes



To avoid channeling:

- Use a thin SiO_2 "screening" layer
- Implant at an angle (e.g. 7°)



S/D asymmetry.

As implanted, dopants are not electrically active yet. Activation: by annealing, dopants occupy substitutional sites.

How do we measure the concentration profile?

Secondary Ion Mass Spectrometry (SIMS)

See Wikipedia: SIMS