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)/SiO₂ 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

\begin{align*}
O₂, H₂O & \\
\text{diffusion} & \\
SiO₂ & \\
\text{reaction} & \\
Si & \\
\end{align*}

\begin{align*}
Si + O₂ & \rightarrow SiO₂ \\
Si + 2H₂O & \rightarrow SiO₂ + 2H₂ \\
\end{align*}

1.3² ≈ 2.2
Active region and field formation

Oxidation Kinetics

\[ F_1 = F_2 = F_3 \]
Introduce two parameters $A$ & $B$, ($T$-dependent)

$$x_{0x} = \frac{A}{2} \left[ \sqrt{1 + \frac{t+2}{A^2/4B}} - 1 \right]$$

$t$: time

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

$$T = \frac{x_i^2 + Ax_i}{B}$$

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

$x_{0x} = x_{0x}(t+T)$ is linear-parabolic

For small $t+T$ (i.e., initial stage, $\frac{t+T}{A^2/4B} \ll 1$):

$$x_{0x} \approx \frac{B}{A} (t+T)$$ — linear

How to get to this approximation?
For large $t + t$,

$$x_{ox} = \sqrt{B(t + t)}$$

**Example:** $t = 0$

![Graph](image_url)
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 straggling of the how far this moves during subsequent annealing. With decreasing dev the implant straggle under the mask edge is becoming a more imp 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 sufficiently mask an implant. In order to act as an efficient mask, the thikn should be large enough that the tail of the implant profile in the siliconified 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

\[
C'(x) - C'_{\text{avg}} \left( \frac{(x_m - R_p^*)^2}{\sigma^2} \right) < 0
\]
Figure 8-3 Plot of the range \( R_x \) (top) and standard deviation \( \Delta R_x \) (bottom) of common dopants in crystalline silicon tilted and rotated to simulate a random direction. (After [8.1].)

\[
C(x,y) = C_{\text{vert}}(x) \exp\left(-\frac{y^2}{2\Delta R_x^2}\right)
\]

Any layer thick enough to capture the implanted ions can be used as a \( n \) layer. For example, photoresist is often used as a convenient mask, because it is performed at room temperature. Near a mask edge, the profile is dominated lateral straggling 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 l
Implantation 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.

Δ Channeling

At low incident angles, an ion can channel through between crystalline planes.
To avoid channeling:
- Use a thin SiO₂ "screening" layer
- Implant at an angle (e.g. 7°)

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