Semiconductor Process Presentation

2019.12.05

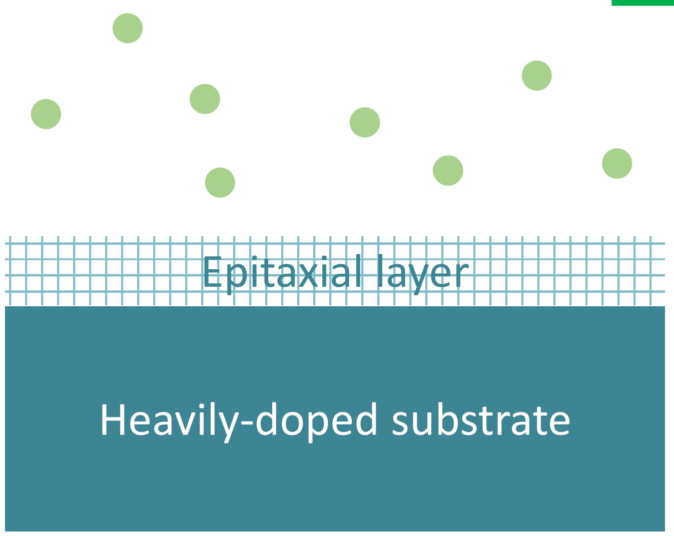
Contents

1. Epitaxy

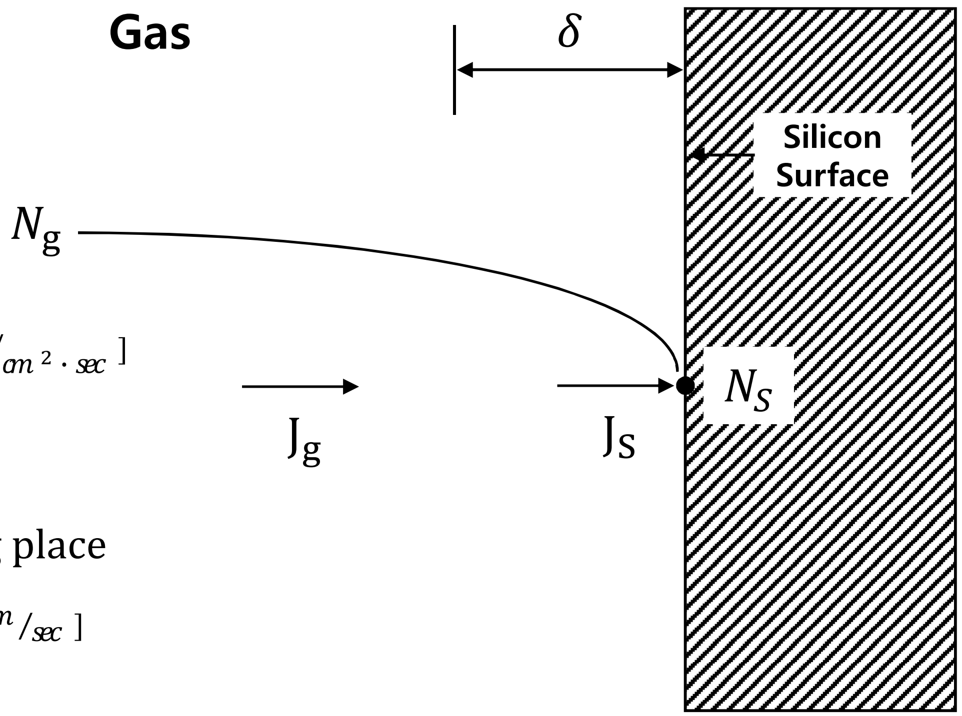
Epitaxy

(Direct Vapor Deposition)

- Vapor-Phase Epitaxy (VPE)
- Liquid-Phase Epitaxy (LPE)
- Molecular-Beam Epitaxy (MBE)



2. Vapor-Phase Epitaxy (VPE)



$$J_S = k_s N_S \quad [\#/\mathrm{cm}^2\cdot\mathrm{sec}]$$

k_s is the surface reaction rate constant $[\mathrm{cm}/\mathrm{sec}]$

N_S is the surface concentration $[\#/\mathrm{cm}^3]$

$$J_g = (\overline{D_g}/\delta)\cdot(N_g - N_s) = h_g\cdot(N_g - N_S) \quad [\#/\mathrm{cm}^2\cdot\mathrm{sec}]$$

$\overline{D_g}$ is an effective diffusion constant $[\mathrm{cm}^2/\mathrm{sec}]$

δ is the distance over which the diffusion is taking place

h_g is the vapor phase mass transfer coefficient $[\mathrm{cm}/\mathrm{sec}]$

$$N_s = \frac{h_g}{h_g + k_s}\cdot N_g$$

$$J_S = k_s N_S$$

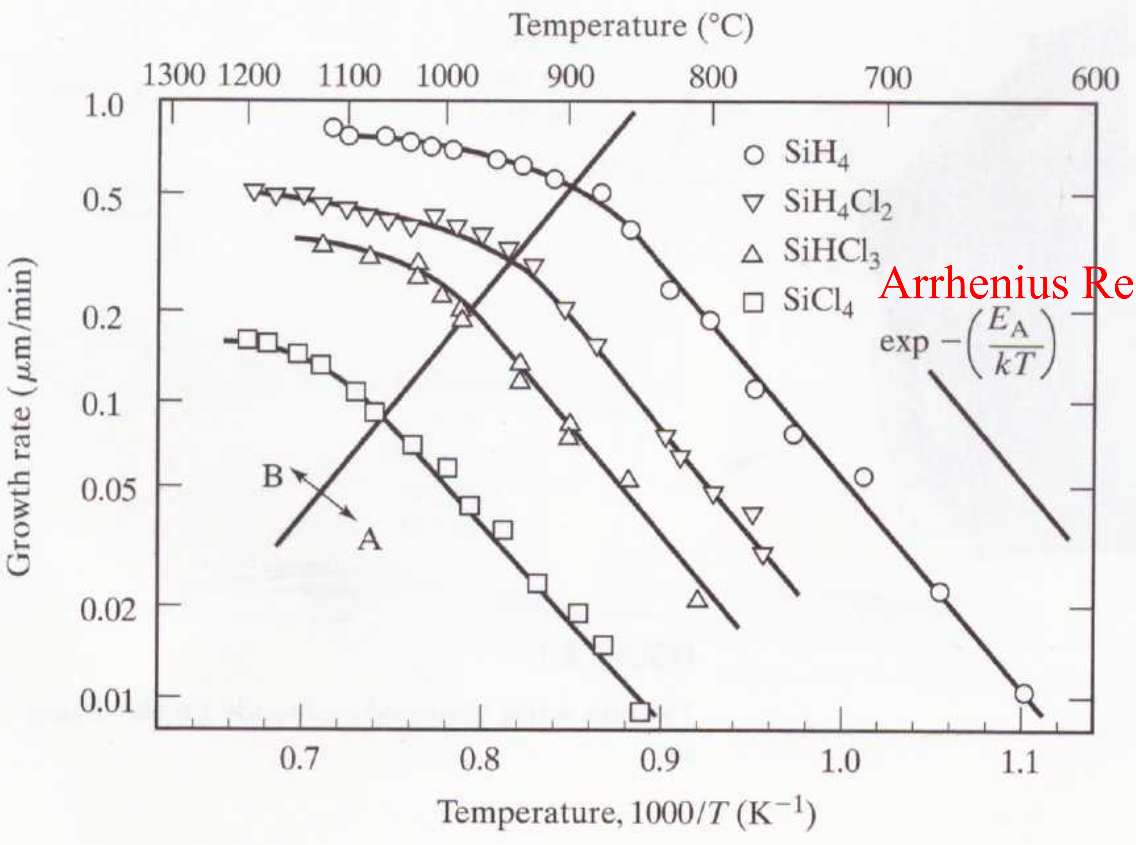
$$v = \frac{J_S}{N} = \frac{k_s h_g}{k_s + h_g}\cdot\frac{N_g}{N} \;\; \begin{cases} v = h_g\cdot\dfrac{N_g}{N} & (\text{mass transfer limited}, k_s \gg h_g) \\ \\ v = k_s\cdot\dfrac{N_g}{N} & (\text{surface reaction limited}, h_g \gg k_s) \end{cases}$$

v is growth rate $[\mathrm{cm}/\mathrm{sec}]$

2. Vapor-Phase Epitaxy (VPE)

A: Surface-reaction-limited region

B: Mass-Transfer-limited region



Arrhenius Relationship

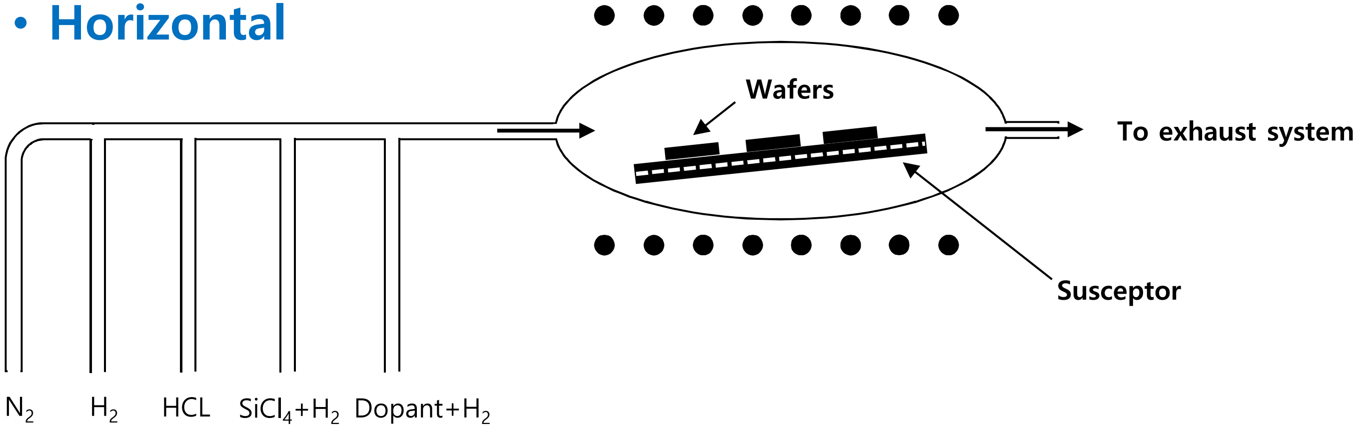
FIGURE 6.10

Temperature dependence of the silicon epitaxial growth process for four different sources. The growth rate is surface-reaction-limited in region A and is mass-transfer-limited in region B. Reprinted with permission from Philips Journal of Research from Ref. [3].

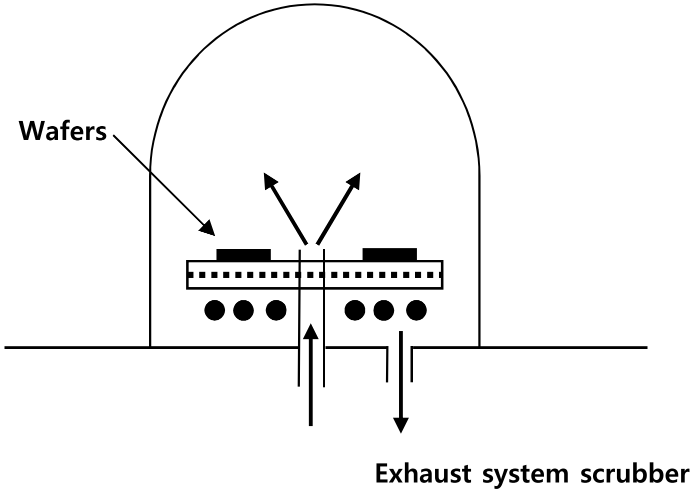
2. Three Common Types of VPE Reactors

- → Gas flow
- ● RF heating
- ○ Radiant heating

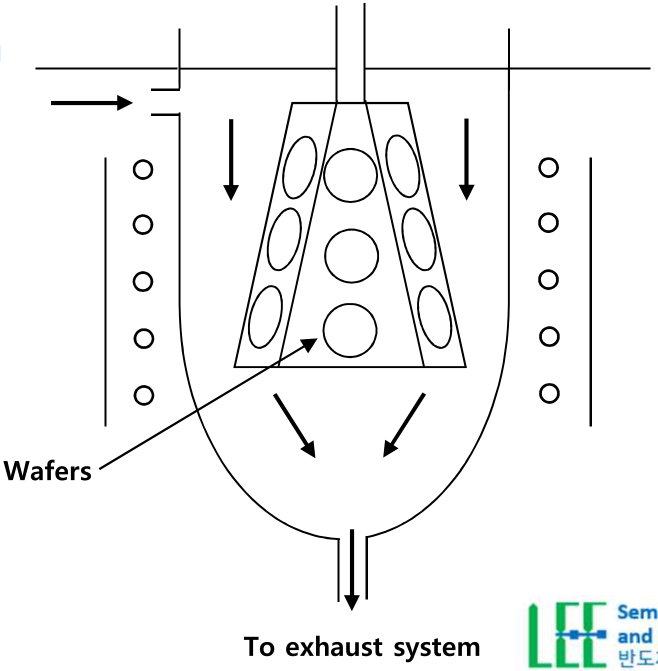
- Horizontal



- Pancake

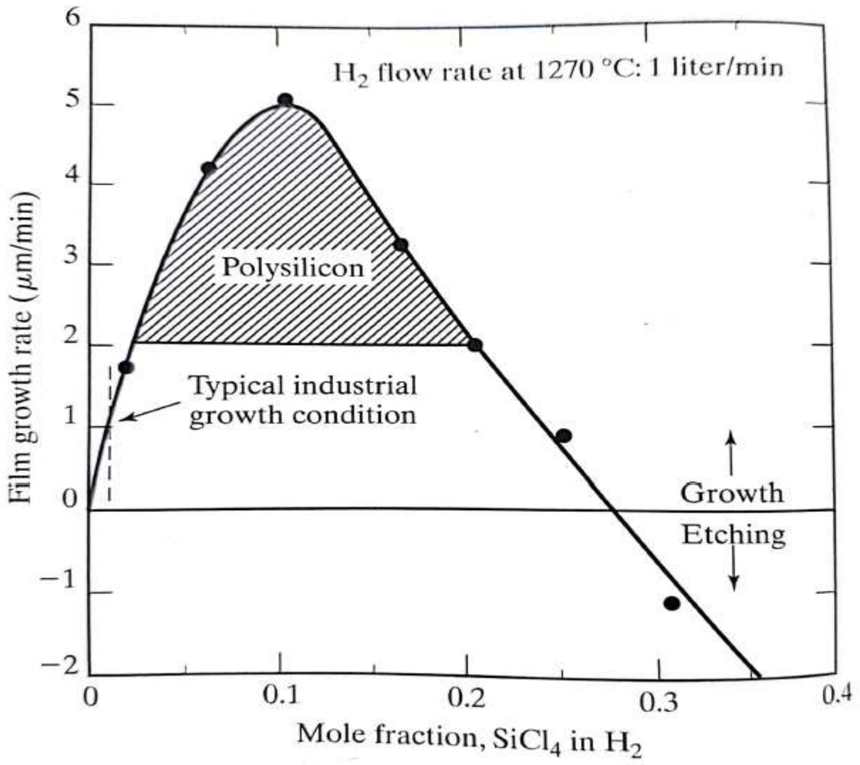


- Barrel system



2. VPE's Reactions

1. $SiCl_4$ (gas) + $2H_2$ (gas) $\overset{1200℃}{\leftrightarrow}$ Si (solid) + 4HCl (gas)
2. $SiCl_4$ (gas) + Si (solid) $\leftrightarrow$ $2SiCl_2$ (gas)
3. SiH_4 (gas) $\xrightarrow{650℃}$ Si (solid) + $2H_2$ (gas)



$SiCl_4$ / H_2

- **The increase of Mole Fraction**

→ Etching

- **The increase of Growth Rate**

→ Polysilicon

3. Doping of Epitaxial Layers

Enhancing the growth rate

● : $SiCl_4$ & H_2 / SiH_4

● : $\mathbf{B}_2H_6$(Diborane)

/ $\mathbf{As}H_3$(Arsine)

/ $\mathbf{P}H_3$(Phosphine) / etc.

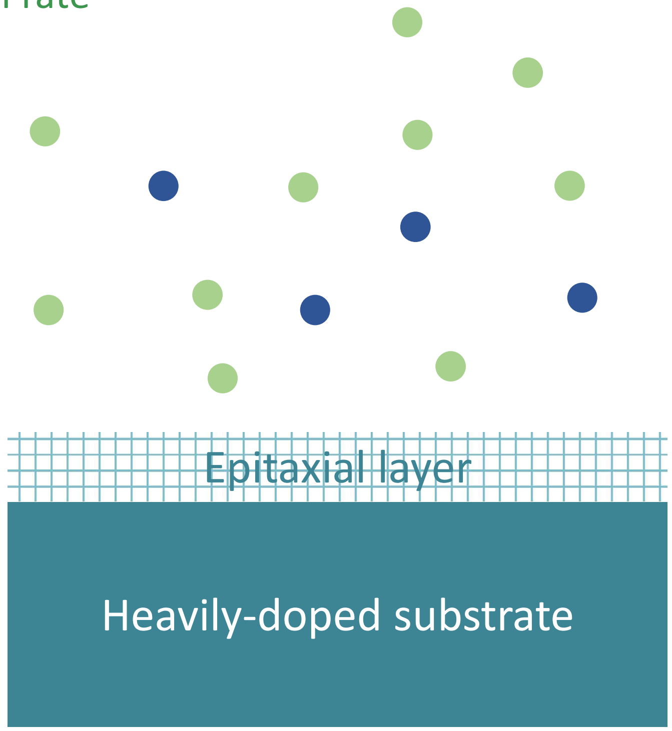
→ Gas source of imputrities

Slowing down
the growth rate

Doping control

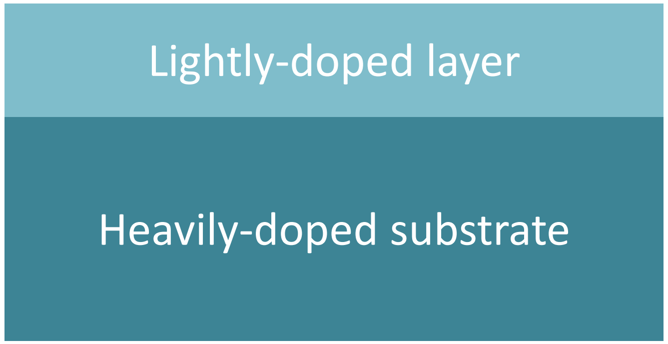
→ by varying the partial pressure

of the dopant species

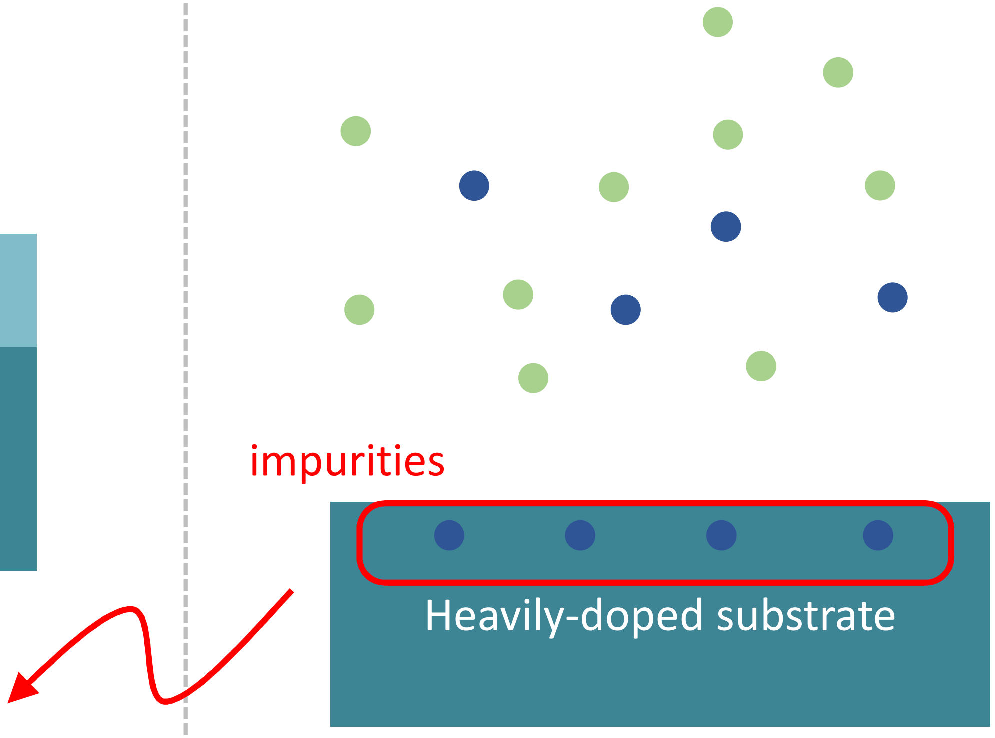


650 ~ 1200 ℃

3. Doping of Epitaxial Layers



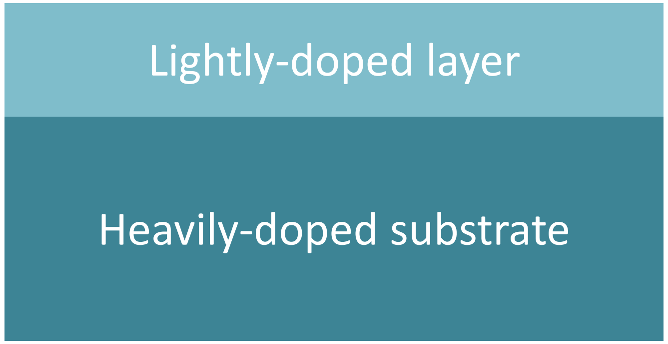
< Autodoping >



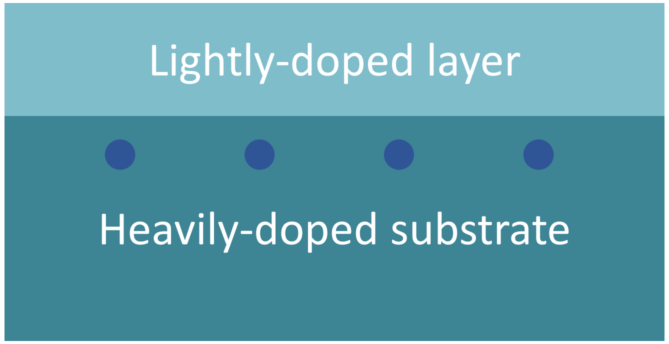
- Evaporate from the wafer
- Liberated by **Cl** etching

650 ~ 1200 ℃

3. Doping of Epitaxial Layers



< Out-diffusion >

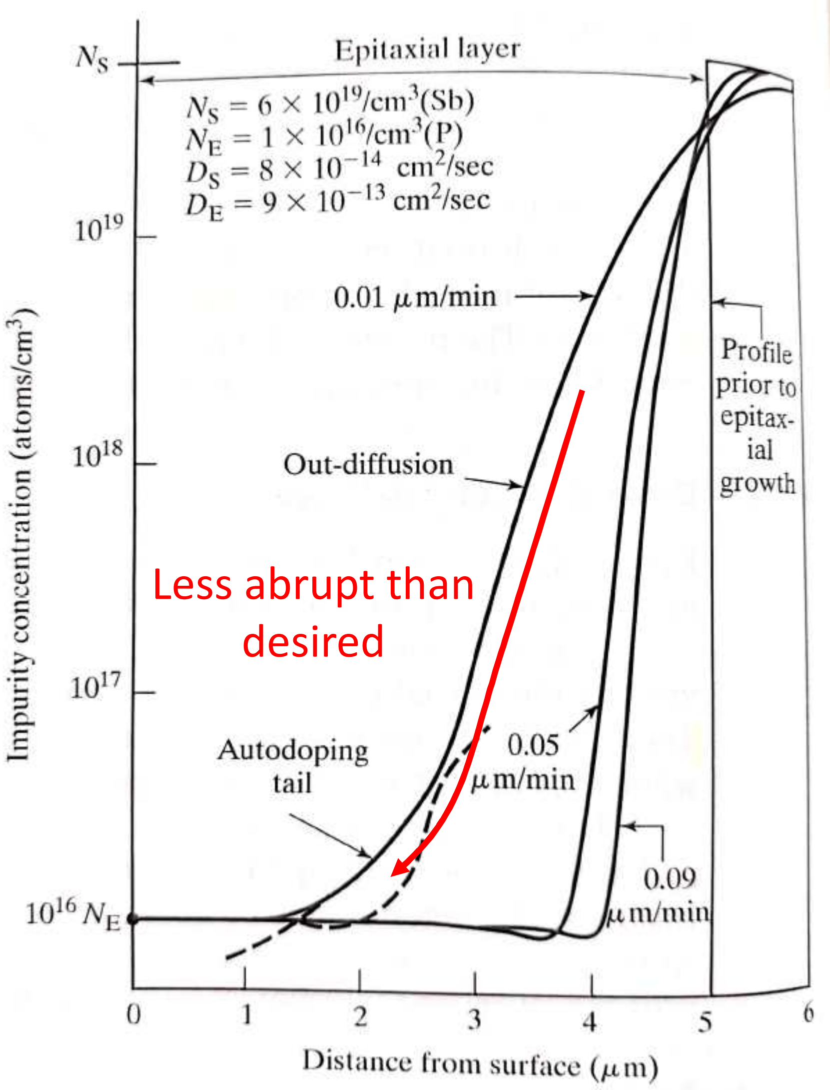


650 ~ 1200 ℃

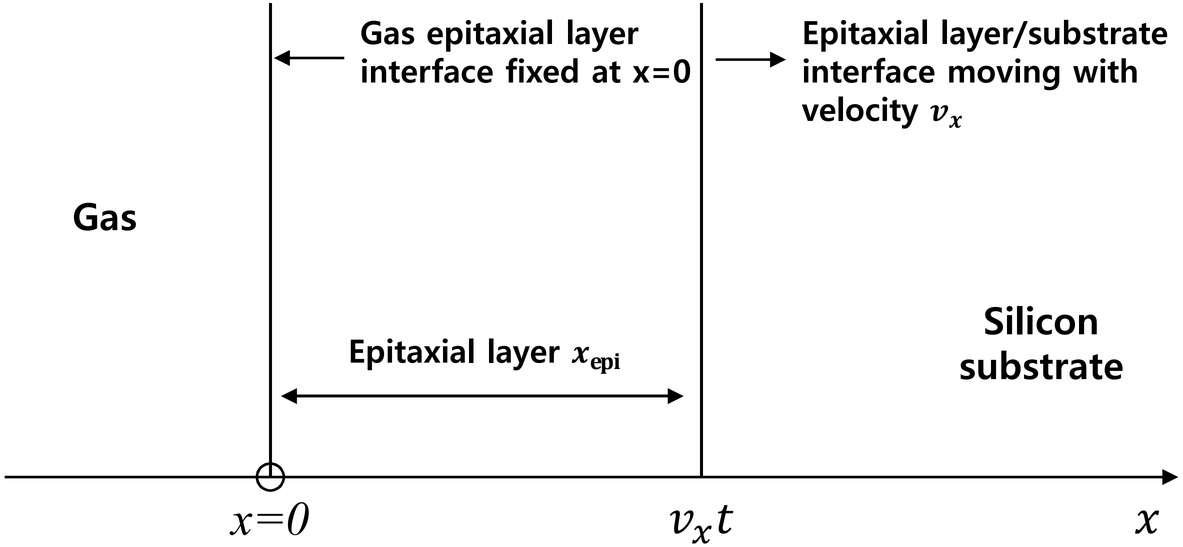
→ A common problem with buried layer

3. Doping of Epitaxial Layers

at 1150℃



4. Out-Diffusion's Problem



Gas

Gas epitaxial layer interface fixed at x=0

Epitaxial layer/substrate interface moving with velocity v_x

Epitaxial layer x_{epi}

Silicon substrate

- $D\dfrac{\partial^2 N}{\partial x^2} = \dfrac{\partial N}{\partial t} + v_x \dfrac{\partial N}{\partial x}$

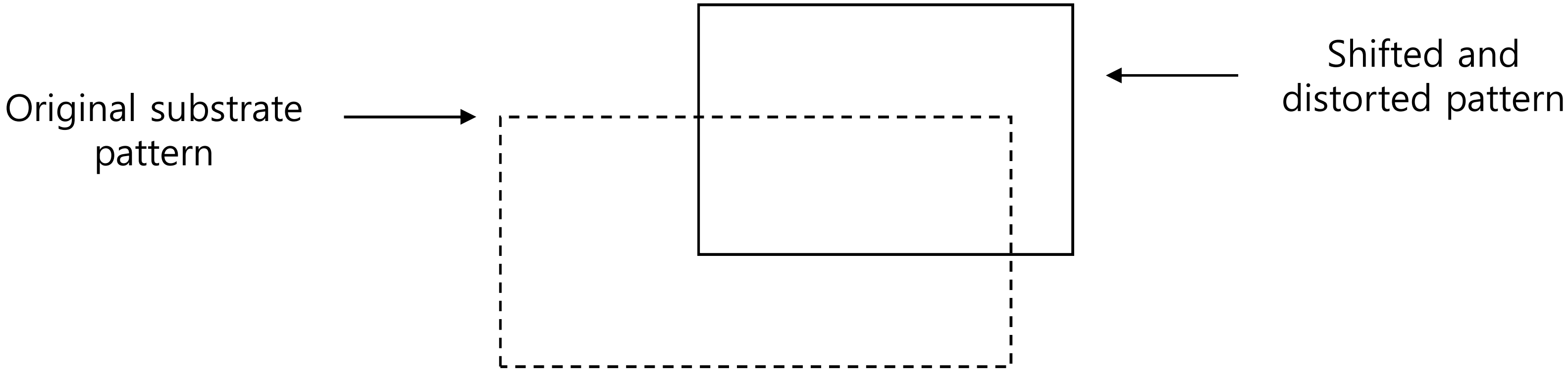
The growth of an undoped epi-layer on a uniformly doped substrate

- $N_1(x,t) = \dfrac{N_S}{2}\left[1 + erf\ \dfrac{x - x_{epi}}{2\sqrt{D_S t}}\right]$ $(B.C.: N(x,0) = N_S = N(\infty, t)\ \&\ J_x = (h + v_x)N(0,t))$
- $N_2(x,t) = \dfrac{N_S}{2}\left[erf\ c\,\dfrac{x - x_{epi}}{2\sqrt{D_E t}} + \exp\dfrac{v_x x}{D_E}\,erfc\ \dfrac{x + x_{epi}}{2\sqrt{D_E t}}\right]$ $(B.C.: N(0,t) = N_E\ \&\ N(\infty, t) = 0 = N(x,0))$

The growth of a doped epi-layer on an undoped substrate

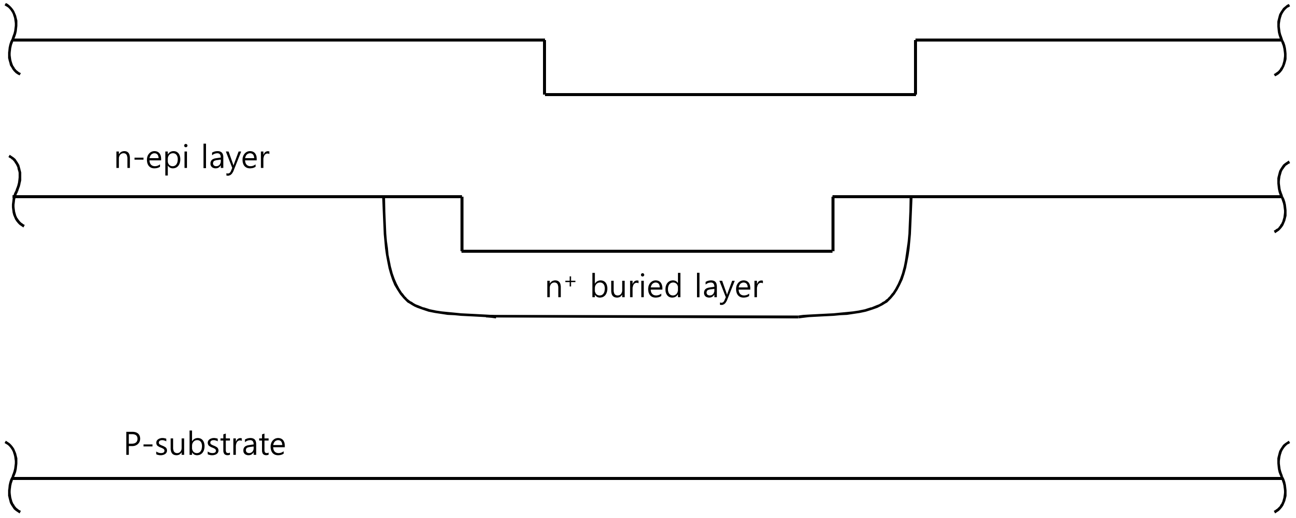
- $N(x,t) = N_1(x,t) + N_2(x,t)$

4. An Additional Problem : Pattern Shift



Original substrate pattern

Shifted and distorted pattern



n-epi layer

n+ buried layer

P-substrate