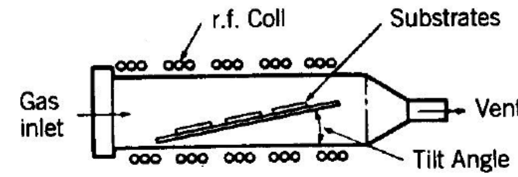
Epitaxy

Mathews-Blakeslee Defect Thickness

$$h_c = \frac{b\left(1-\frac{\nu}{4}\right)}{4\pi\left|\frac{a_s - a_l}{a_s}\right|(1+\nu)} \ln 1 + \frac{h_c}{b} \qquad \nu \approx 0.3 \qquad b \approx 4\ \text{Å}$$



Chemical Vapor Deposition – Vapor Phase Epitaxy

A few microns per hour

$$J = \frac{\beta P}{\sqrt{2\pi m k_B}}$$

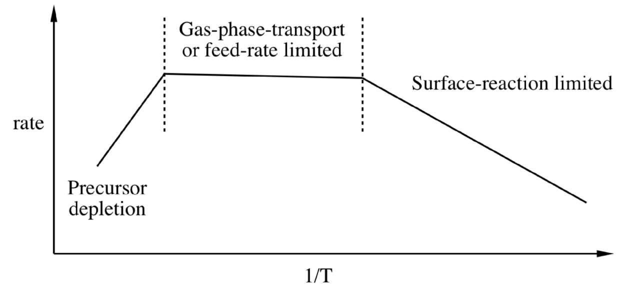
$$K = \exp\left(\frac{\Delta G}{k_B T}\right)$$

if $K < 1$, reactants favored
if $K > 1$, products favored

$$R = \frac{c_s}{N} = \frac{c_g}{N}\left(\frac{h_g k_s}{h_g + k_s}\right)$$

$$R \propto \exp\left(-\frac{\Delta E}{k_B T}\right)$$

k is the rate constant
h is the mass transfer constant
N is crystal density

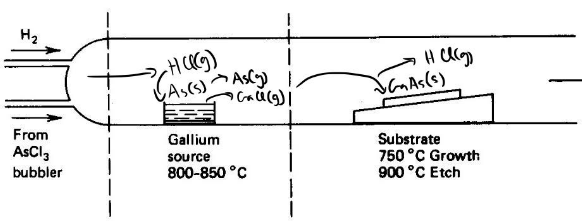


Silicon

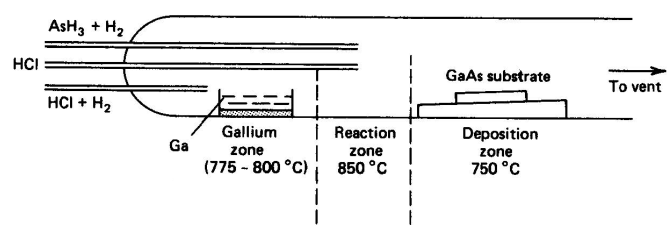
$SiH_4 \rightarrow Si + 2\ H_2$
$SiH_2Cl_2 \rightarrow Si + 2\ HCl$
B_2H_6, PH_3, and AsH_3 are used as dopants

GaAs

$Ga(CH_2CH_3)_3$, AsH_3, $In(CH_3)_3$, $Al(CH_2CH_3)_3$
H_2S, H_2Se, SiH_4 are used as dopants



Schematic for the halide process.



Schematic for the hydride process.

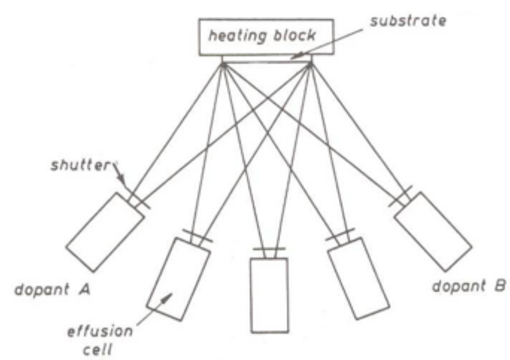
$SiH_4 + O_2 \rightarrow SiO_2$ 420C   TEOS $+ O_2 \rightarrow SiO_2$ 720C $SiH_4 + N_2O \rightarrow SiO_2$ 275C

$2\ MoCl_5 + 5\ H_2 \rightarrow 2\ Mo + 10\ HCl$ Self-aligned contact: $2\ WF_6 + 3\ Si \rightarrow 2W + 3\ SiF_4$

Physical Vapor Deposition – Molecular Beam Epitaxy

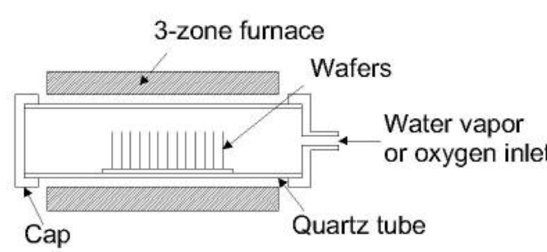
$$J = 1.12 \times 10^{22}\ \frac{P A_e \cos\theta}{l^2 \sqrt{M}\sqrt{T}}$$ where M is molar mass

R = flux/crystal density
Composition is fractional pressure
A few microns per hour



Oxidation – Silicon Only

Dry $Si + O_2 \rightarrow SiO_2$ Slower, consistent ε
Wet $Si + H_2O \rightarrow SiO_2 + 2H_2$ Faster, variable ε
HF dissolves SiO_2 but not Si
Cuts into wafer by $0.467\ x_{ox}$
High B conc. improves diffusion
High P conc. improves reaction

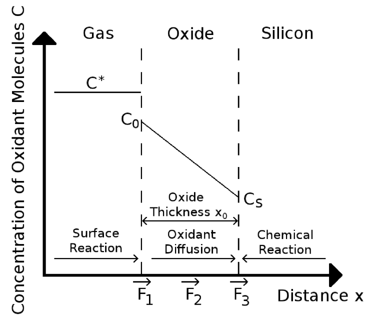


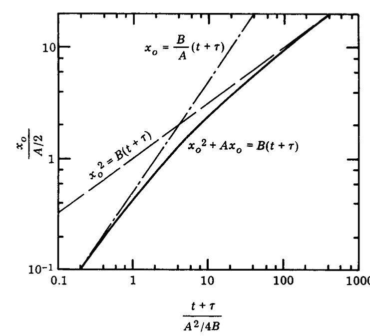
Deal-Grove Model

$$x_{ox}^2 + A\,x_{ox} = B\,(t + \tau)$$

$$A = 2D\left(\frac{1}{k_s} + \frac{1}{h}\right) \quad B = \frac{2DC^*}{N} \quad \tau = \frac{x_i^2 + Ax_i}{B}$$

$$\frac{B}{A} \approx C^* \frac{k_s}{N} \text{ if } h >> k_s$$





Lithography

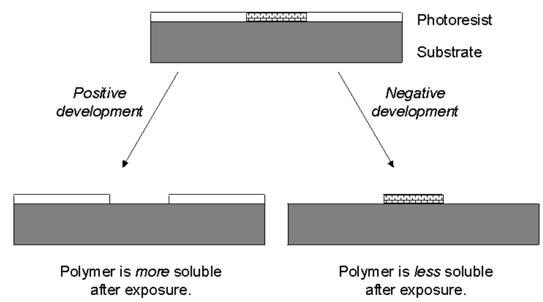
ArF light is 193 nm

$\sin\theta = \frac{1.22}{d}\lambda$ where d is aperture diameter

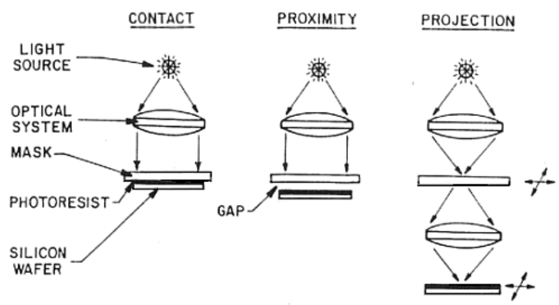
Numerical aperture is $n\ \sin\theta$

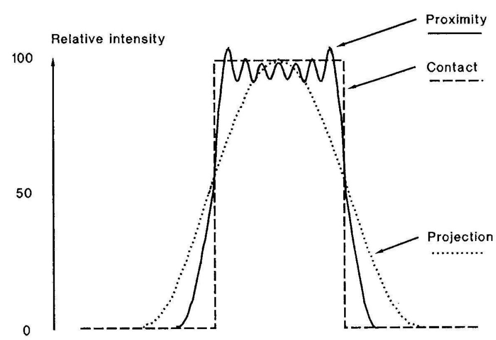
Feature size, $W_{min} \approx \frac{0.6}{n\ \sin\theta}\lambda$

Depth of focus, $\sigma = \frac{1}{n^2 \sin^2\theta}\lambda$



Negative light induces cross-linking
Positive lights breaks bonds





Etches

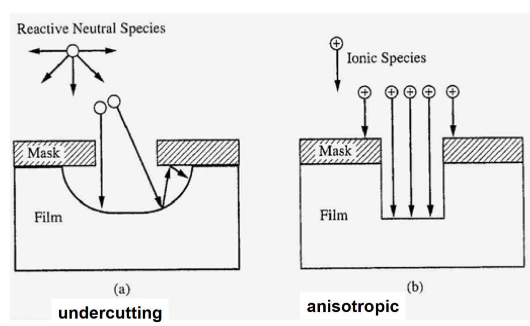
Wet – there are many recipes
(111) is the slow plane for anisotropic wet etching in Si (KOH or TMAH)

HNO3 then HF
Fast etch 49% HF
Through mask ~3 molar HF with NH4F
Cleaning Dilute HF

2 GaAs + 6 H2O → Ga2O3 + As2O3 + $12H^+$
Ga2O3 and As2O3 dissolve in acids and bases
Caro's etch: H2SO4, H2O2, H2O
(diffusion limited so flat surface

Dry and Reactive Ion Etching

Argon bombardment at 1 keV mills most materials at 10-100 nm/min
Halocarbons etch through the radical formation of volatile products



Deposition

Evaporation can non-selectively deposit metals without damage
Sputtering (Ar) can dislodge substances which then shower the wafer
Damascene: etch figure, fill with metal, planarize