3.155J/6.152J
Fall Term, 2005

Useful Equations and Figures

Constants: Boltzman const: $k_B = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K,
Electron charge, $q = 1.6 \times 10^{-19}$ Coul.
1 atm = 760 Torr = 10^5 Pa

Ideal gas: $PV = Nk_BT$, $N/V = n = C$ (concentration), $J_x = \dfrac{n\bar{v}_x}{2}$.

Gas kinetics: $\bar{v}_x = \sqrt{\dfrac{2k_BT}{\pi m}}$, Mean free path: $\lambda = \dfrac{k_BT}{\sqrt{2}\pi d^2 P}$, d = molecular diameter.

$$J = \frac{P}{\sqrt{2\pi k_B T m}},\ m = \text{species mass.}$$

Oxidation: Thickness x_0 after time t; $x_0^2 + Ax_0 = B(t + \tau)$

$$B/A = C_0k_s/N, \qquad B = 2D_{ox}C_0/N$$

C_0 is oxidant concentration at surface,
k_s = oxidation rate constant, $k_s = k_0 \exp(-E_a/k_BT)$;
N = number of oxide molecules per unit *film* volume,
τ = time offset associated with pre-existing oxide of thickness x_0.

CVD: Gas flux across concentration gradient: $J = h_g(C_g - C_s)$, C_s = concentration surface, $h_g = D/\delta_{ave}$, average deal-layer thickness.
Flux for chemical reaction: J (#/(vol-s) = $k\, C_s$, where $k = k_o\exp[-\Delta G/(k_BT)]$.
CVD film growth velocity: $v_f = \dfrac{J}{N_f} = \dfrac{C_g/N_f}{\dfrac{1}{h} + \dfrac{1}{k}}$,
where N_f is (number of species *deposited*)/cm^3.

Diffusion: Diffusion length: $a = 2(Dt)^{1/2}$; $D = D_0\exp[-E/k_BT]$;

$$D = D^0 + D^-(n/n_i) + D^{--}(n/n_i)^2\ldots$$

Fixed dose: $$C(z,t) = \frac{Q}{\sqrt{\pi Dt}}\exp\left[-\frac{z^2}{4Dt}\right] = C(0,t)\exp\left[-\frac{z^2}{4Dt}\right]$$

Inexhaustible source: $C(z,t) = C_{surf}\,\mathrm{erfc}\left[\dfrac{z}{2\sqrt{Dt}}\right]$, Dose $\equiv Q = \displaystyle\int_0^\infty C(z,t)\,dz = \frac{2\sqrt{Dt}}{\sqrt{\pi}}C_0$.

Ion implantation: Concentration profile: $C(x) = C_p \exp\left(-\dfrac{(x - R_p)^2}{2\Delta R_p^2}\right)$.

$C_p = Q/[(2\pi)^{1/2}\,\Delta R_p]$ cm^{-3}.

Concentration profile after diffusion: $C(x)=\frac{Q}{\sqrt{2\pi(\Delta R_p^2+2Dt)}}\exp\left(-\frac{\left(x-R_p\right)^2}{2(\Delta R_p^2+2Dt)}\right).$

Energy transfer in collision of M_1 and M_2: $\Delta E = E_1\frac{4M_1M_2}{\left(M_1+M_2\right)^2}\cos^2\theta$

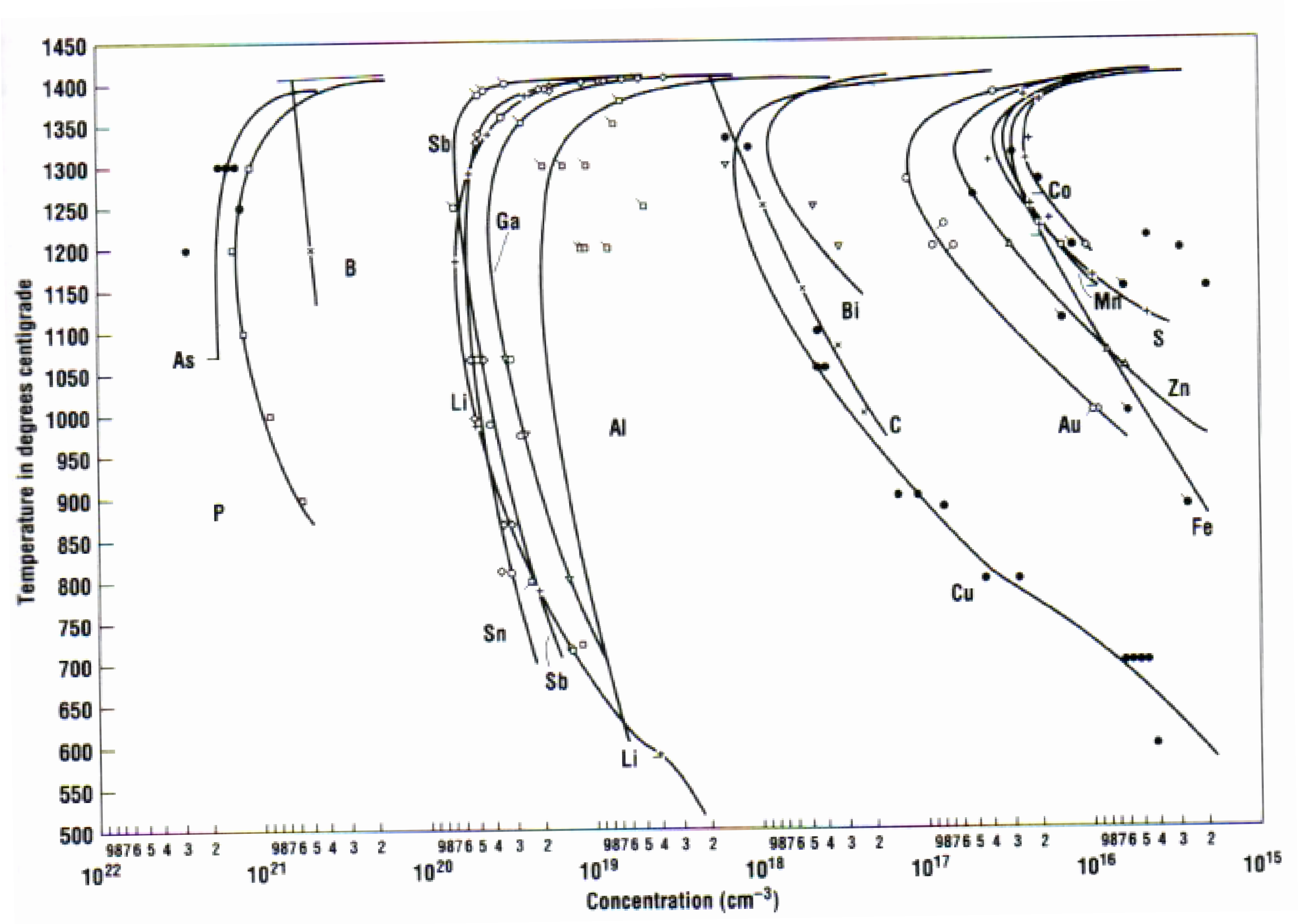
Electrical: Resistivity, $R=\rho\, l/A$ (Ohm), Sheet resistance, $R_s = =\rho/t$ (Ohm/Sq)

Carrier mobility, $\mu=\frac{\langle v\rangle}{E}=\frac{\sigma}{ne}=\frac{e\tau}{m^*}$

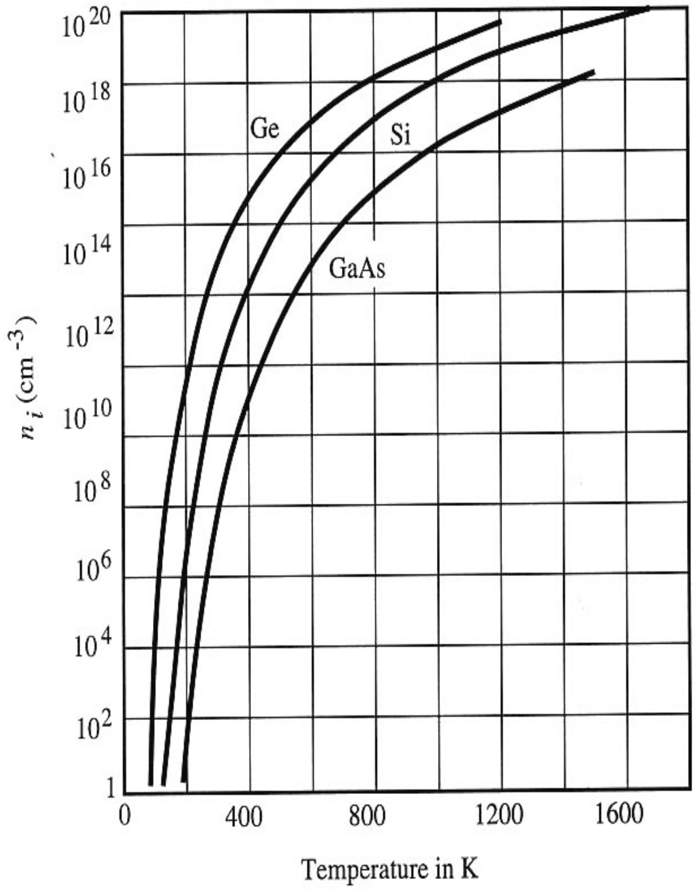
Capacitance, $C=\kappa\varepsilon_0 A/d$ (Farad), $\varepsilon_0 = 8.85 \times 10^{-12}$ (F/m)

Some useful Figures, Tables.

Equilibrium solubility of various species in Si vs Temperature:



Intrinsic carrier concentration vs. temperature



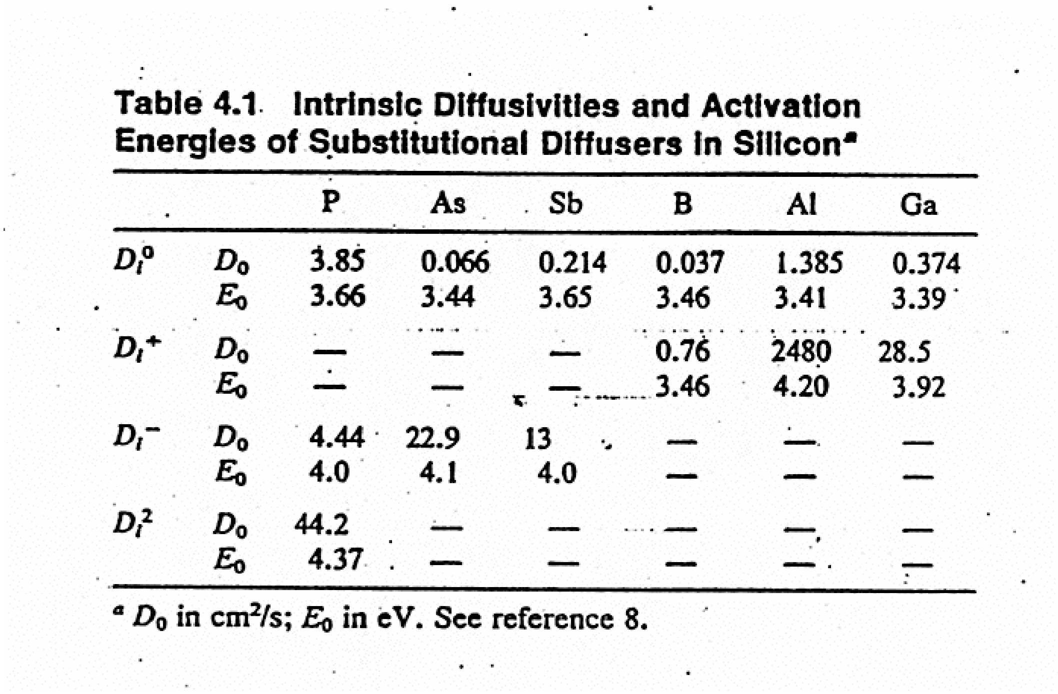


Table 4.1. Intrinsic Diffusivities and Activation Energies of Substitutional Diffusers in Silicon[a]

		P	As	Sb	B	Al	Ga
D_i^0	D_0	3.85	0.066	0.214	0.037	1.385	0.374
	E_0	3.66	3.44	3.65	3.46	3.41	3.39
D_i^+	D_0	—	—	—	0.76	2480	28.5
	E_0	—	—	—	3.46	4.20	3.92
D_i^-	D_0	4.44	22.9	13	—	—	—
	E_0	4.0	4.1	4.0	—	—	—
D_i^2	D_0	44.2	—	—	—	—	—
	E_0	4.37	—	—	—	—	—

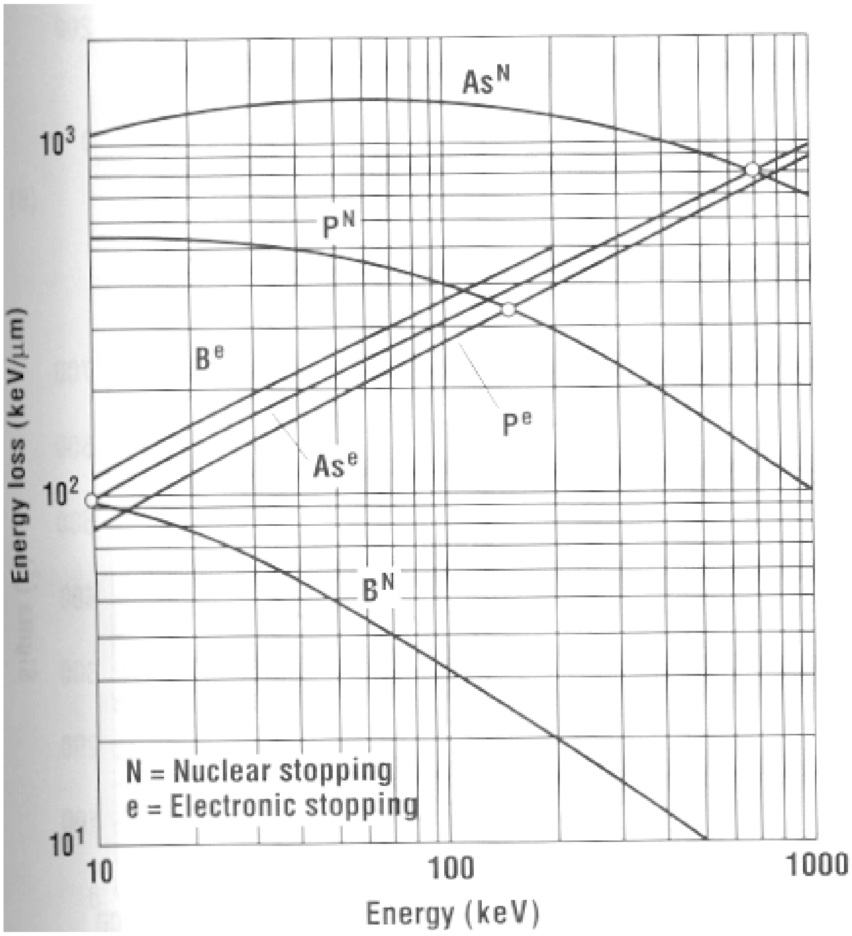
[a] D_0 in cm^2/s; E_0 in eV. See reference 8.

Selected Deal-Grove oxidation parameters for Si.

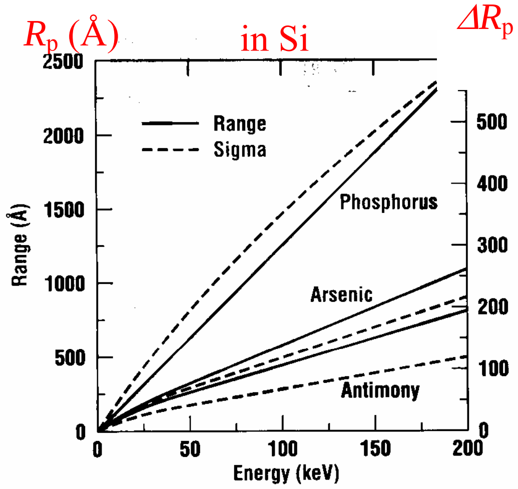
Table 4.1 Oxidation coefficients for silicon (wet oxidation is much faster than dry)

	Dry			Wet (640 torr)	
Temperature (°C)	**A (μm)**	**B (μm²/hr)**	**τ (hr)**	**A (μm)**	**B (μm²/hr)**
800	0.370	0.0011	9	—	—
920	0.235	0.0049	1.4	0.50	0.203
1000	0.165	0.0117	0.37	0.226	0.287
1100	0.090	0.027	0.076	0.11	0.510
1200	0.040	0.045	0.027	0.05	0.720

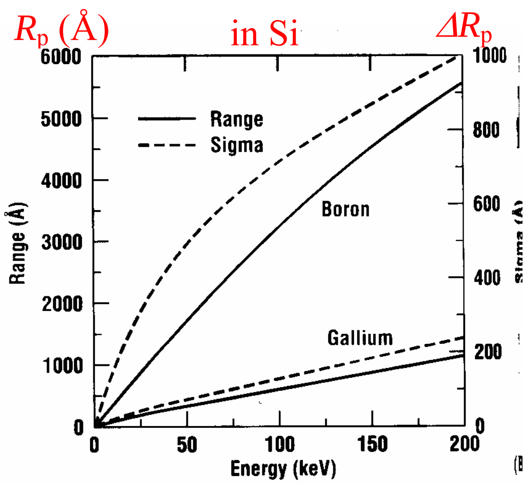
Ion implantation stopping mechanisms

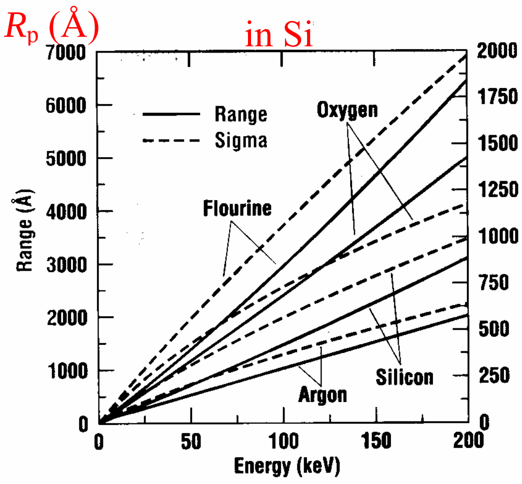


Ion implantation range and width in Si and GaAs



(A)





(C)