	Eg (eV)	μ_n cm^2/V-s	μ_p cm^2/V-s	ε_r	τ_n	τ_p	m_e^*	m_h^*	a (Å)
Si	1.11	1350	480	11.8	10^{-6} s	10^{-7} s	$1.1m_o$	$.56m_o$	5.43
Ge	.67	3900	1900	16	10^{-6} s	10^{-7} s	$.55m_o$	$.37m_o$	5.65
GaAs	1.43	8500	400	13.2	10^{-9} s	10^{-9} s	$.067m_o$	$.48m_o$	5.65

II	III	IV	V	VI
	B	C		
	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In		Sb	Te

Effective mass

$$m^* = \frac{\hbar^2}{\dfrac{d^2E}{dk^2}}$$

Einstein Relation

$$\frac{D}{\mu} = \frac{kT}{q}$$

Equilibrium Fermi Level

$$\frac{dE_F}{dx} = 0$$

Diffusion length

$$L_n \equiv \sqrt{D_n \tau_n}$$
$$L_p \equiv \sqrt{D_p \tau_p}$$

Law of Mass Action

$$n_o p_o = n_i^2$$

Intrinsic Carrier concentration

$$n_i = 2\left(\frac{2\pi kT}{h^2}\right)^{\frac{3}{2}} \left(m_n^* m_p^*\right)^{\frac{3}{4}} e^{-Eg/2kT}$$

Avogadro's number	$N_A = 6.02 \times 10^{23}$ molecules/mole
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ J/K
	$= 8.62 \times 10^{-5}$ eV/K
Electronic charge (magnitude)	$q = 1.60 \times 10^{-19}$ C
Electronic rest mass	$m_0 = 9.11 \times 10^{-31}$ kg
Permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-14}$ F/cm
	$= 8.85 \times 10^{-12}$ F/m
Planck's constant	$h = 6.63 \times 10^{-34}$ J-s
	$= 4.14 \times 10^{-15}$ eV-s
Room temperature value of kT	$kT = 0.0259$ eV
Speed of light	$c = 2.998 \times 10^{10}$ cm/s

	Prefixes:		
1 Å (angstrom) $= 10^{-8}$ cm	milli-,	m-	$= 10^{-3}$
1 μm (micron) $= 10^{-4}$ cm	micro-,	μ-	$= 10^{-6}$
1 nm = 10Å $= 10^{-7}$ cm	nano-,	n-	$= 10^{-9}$
2.54 cm = 1 in.	pico-,	p-	$= 10^{-12}$
1 eV $= 1.6 \times 10^{-19}$ J	kilo-,	k-	$= 10^{-3}$
	mega-,	M-	$= 10^{6}$
	giga-,	G-	$= 10^{9}$

A wavelength λ of 1 μm corresponds to a photon energy of 1.24 eV.

Diode relations:

$$p_n = \frac{ni^2}{Nd}, \quad n_p = \frac{ni^2}{Na}$$

Diode equations

$$\mathrm{I} = \mathrm{qA}\left(\frac{\mathrm{D_p}}{\mathrm{L_p}}\mathrm{p_n} + \frac{\mathrm{D_n}}{\mathrm{L_n}}\mathrm{n_p}\right)\left(\mathrm{e}^{\mathrm{qV/nkT}} - 1\right)$$

Contact Potential

$$\mathrm{Vo} = \frac{\mathrm{kT}}{\mathrm{q}}\ln\left(\frac{\mathrm{N_a N_d}}{\mathrm{n_i}^2}\right)$$

Junction Width and Capacitance

$$W = \left[\frac{2\varepsilon(V_o - V)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{\frac{1}{2}}$$

$$|Q| = qA\frac{N_a N_d}{N_a + N_d}W$$

$$C_j = \left|\frac{dQ}{d(V_o - V)}\right| = \frac{A}{2}\left[\frac{2q\varepsilon}{(V_o - V)}\frac{N_a N_d}{N_a + N_d}\right]^{\frac{1}{2}}$$

Maxi Efield

$$Eo = -\frac{q}{\varepsilon}N_d x_{no} = -\frac{q}{\varepsilon}N_a x_{po}$$

Length of Xn and Xp

$$x_{p0} = \left\{\frac{2\varepsilon(V_o - V)}{q}\left[\frac{N_d}{N_a(N_a + N_d)}\right]\right\}^{\frac{1}{2}}$$

$$x_{n0} = \left\{\frac{2\varepsilon(V_o - V)}{q}\left[\frac{N_a}{N_d(N_a + N_d)}\right]\right\}^{\frac{1}{2}}$$

SS Capacitance and Conductance

$$G_s = \frac{dI}{dV} = \frac{q}{kT}I$$

$$C_s = \frac{dQ_p}{dV} = \frac{q}{kT}I\tau_p(p^+/n), = \frac{dQ_n}{dV} = \frac{q}{kT}I\tau_n(p/n^+)$$

$$i(ac) = G_s v(ac) + C_s\frac{dv(ac)}{dt}$$

Gain for pnp BJT

$$\gamma = \left[1 + \frac{W_b n_n \mu_n^p}{L_n^p p_p \mu_p^n}\right]^{-1} \qquad B = \frac{I_C}{I_{Ep}} = 1 - \frac{W_b^{\ 2}}{2 \times L_p^{\ 2}} \qquad \alpha = B\gamma \quad \beta = \frac{\alpha}{1-\alpha}$$

Gain for npn BJT

$$\gamma = \left[1 + \frac{W_b p_p \mu_p^n}{L_p^n n_n \mu_n^p}\right]^{-1} \qquad B = \frac{I_C}{I_{En}} = 1 - \frac{W_b^{\ 2}}{2 \times L_n^{\ 2}} \qquad \alpha = B\gamma \quad \beta = \frac{\alpha}{1-\alpha}$$

Turn on - time :

$$t_s (\text{when } Q_b(t)/t_s = I_C) = \tau_p \ln\left(\frac{1}{1 - I_C/\beta I_B}\right)$$

Turn off - time :

$$t_{sd} = \tau_p \ln\left(\frac{\beta I_B}{I_C}\right)$$

$$f_T = \frac{1}{2\pi\tau_d} \qquad \tau_d = \tau_E + \tau_{WC} + \tau_t$$

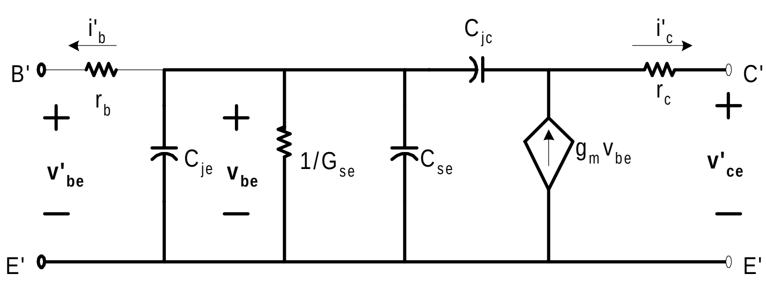
$$\tau_d = \tau_E + \tau_{WC} + \tau_t$$

$$\tau_E = r_e(C_e + C_c + C_p) = \frac{kT}{qI_E}(C_e + C_c + C_p)$$

$$\tau_{WC} = \frac{W_{CB}}{2\langle v_s \rangle}$$ Here, W_{CB} is the length of the CB depletion width.

$$\tau_t = \frac{W_B^{\ 2}}{2D}$$

$$f_{max} = \left(\frac{f_T}{8\pi R_B C_c}\right)^{\frac{1}{2}}$$



MOS:

$$V_T = \varphi_{ms} - \frac{Q_i}{C_i} - \frac{Q_d}{C_i} + 2\varphi_F, \quad \varphi_F = .0259\ln\left(\frac{N_a}{n_i}\right)(\text{NMOS})$$

$$V_T = \varphi_{ms} - \frac{Q_i}{C_i} - \frac{Q_d}{C_i} - 2\varphi_F, \quad \varphi_F = .0259\ln\left(\frac{N_d}{n_i}\right)(\text{PMOS})$$

Linear Region:

$$V_D < V_G - V_T\,(\text{NMOS}), \quad V_D > V_G - V_T\,(\text{PMOS})$$

$$g_m = \frac{Z}{L}\mu_n C_i V_D\,(\text{NMOS}), \quad g_m = -\frac{Z}{L}\mu_p C_i V_D\,(\text{PMOS})$$

$$I_D = \frac{Z}{L}\mu_n C_i\left[(V_G - V_T)V_D - \frac{1}{2}V_D^{\,2}\right](\text{NMOS})$$

$$I_D = -\frac{Z}{L}\mu_p C_i\left[(V_G - V_T)V_D - \frac{1}{2}V_D^{\,2}\right](\text{PMOS})$$

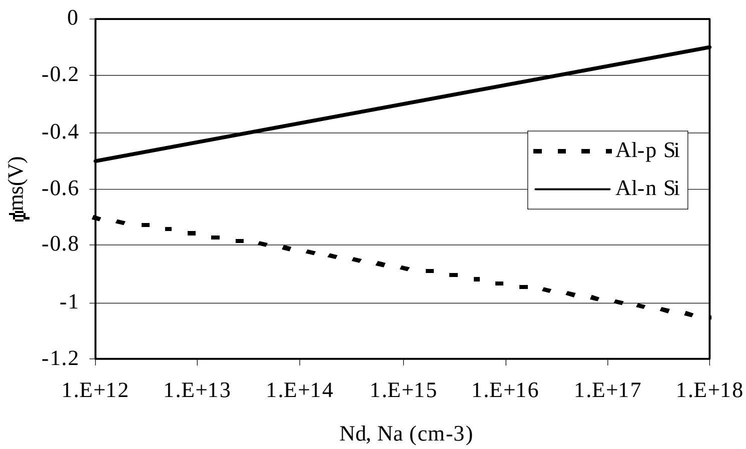
φ_{ms} Get from chart (both n and p channel)

$$C_i = \frac{(3.9)(8.885\times10^{-14}\ \text{F/cm})}{d(cm)} \quad \text{(both n and p channel)}$$

Q_i = Given to you by process engineer.

$$Q_d = -2(\varepsilon_s q N_a \varphi_F)^{\frac{1}{2}}(\text{NMOS}), \quad Q_d = 2(\varepsilon_s q N_d \varphi_F)^{\frac{1}{2}}(\text{PMOS}),$$

Variation of the metal-semiconductor work function



Saturation Region ($V_{DSAT} = V_G - V_T$):

$$V_D \geq V_G - V_T\,(NMOS), \quad V_D \leq V_G - V_T\,(PMOS)$$

$$g_{m(sat)} = \frac{Z}{L}\mu_n C_i V_{DSAT}\,(NMOS)$$

$$g_{m(sat)} = -\frac{Z}{L}\mu_p C_i V_{DSAT}\,(PMOS)$$

$$I_{D(sat)} = \frac{Z}{2L}\mu_n C_i V_{DSAT}^{\,2}\,(NMOS)$$

$$I_{D(sat)} = -\frac{Z}{2L}\mu_p C_i V_{DSAT}^{\,2}\,(PMOS)$$

$$f_T = \frac{g_m}{2\pi C_i Z L}, \text{ In General} \qquad f_T = \frac{\langle v_s \rangle}{2\pi L}, \text{ Mobility Saturated } (V_D / L > 10^5 V/cm)$$