Semiconductor Final CheatSheet (chapter5–7)

	$e = 1.602 \times 10^{-19}\text{C}$
Boltzmann's constant	$k = 8.62 \times 10^{-5}\text{eV/K} = 1.38 \times 10^{-23} J/K$
$\varepsilon_0 = 8.85 \times 10^{-14}$	$\varepsilon_i = 3.9\varepsilon_0, \varepsilon_s = 11.8\varepsilon_0$

Si	Ge
$E_g(\text{Si}) = 1.1\text{eV}$	$E_g(\text{Ge}) = .67\text{eV}$
$5 \times 10^{22}\text{atoms/cm}^3$	
$n_i \approx 1.5 \times 10^{10}\text{cm}^{-3}$	$n_i = 2.4 \times 10^{13}\text{cm}^{-3}$
$\mu_n = 1350\text{cm}^3/\text{V-s}, \mu_p = 480\text{cm}^3/\text{V-s}$	$\mu_n = 3900\text{cm}^3/\text{V-s}, \mu_p = 1900\text{cm}^3/\text{V-s}$

intrinsic $\begin{cases} n_i = \sqrt{N_c N_v} e^{-E_g/2kT} \\ n_0 p_0 = n_i^2 \end{cases}$ doped, equilibrium $\begin{cases} n_0 = n_i e^{(E_F - E_i)/kT} \\ p_0 = n_i e^{(E_i - E_F)/kT} \end{cases}$

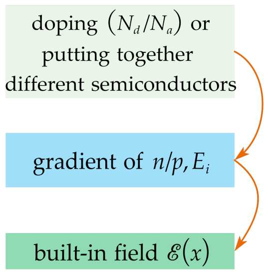
excess carriers, quasi-Fermi level $\begin{cases} n = n_i e^{(F_n - E_i)/kT} \\ p = n_i e^{(E_i - F_p)/kT} \end{cases}$ (for majority carriers $F_n/F_p \approx E_F$)

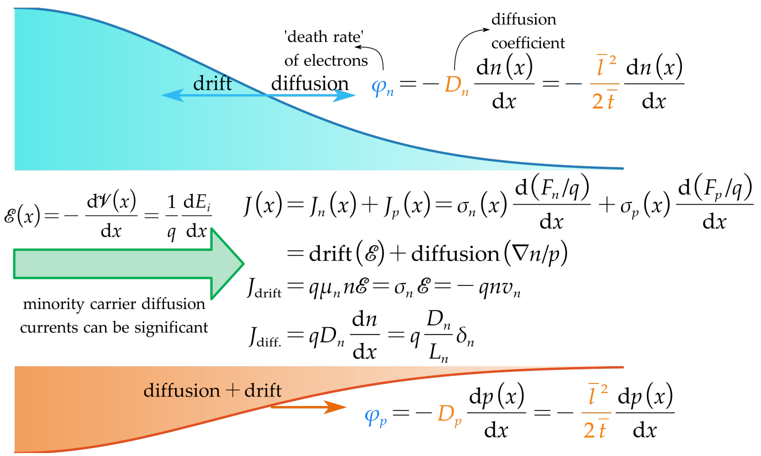
space charge neutrality $\delta n(t) = \delta p(t)$.

$\frac{D}{\mu} = \frac{kT}{q} \simeq 0.026\text{V}$ (eq.)

$L = \sqrt{D\tau}$ (diff.)

$\frac{d^2V}{dx^2} = -\frac{d\mathscr{E}}{dx} = -\frac{\rho}{\varepsilon_s}$





Junctions

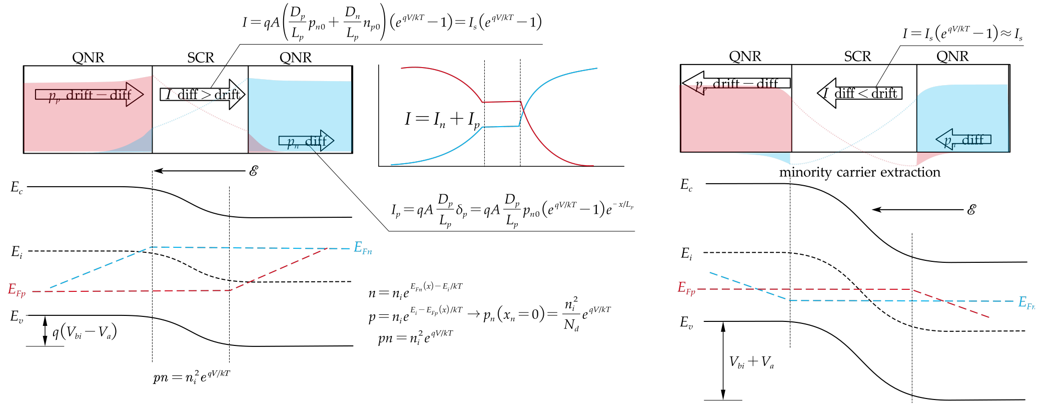
$V_0 = \frac{kT}{q}\ln\frac{p_p}{p_n} = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2}$

$Q = qAx_{n0}N_d = qAx_{p0}N_a$

$W = \sqrt{\frac{2\varepsilon_s V_0}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)}$ $\quad \mathscr{E}_{max} = -\frac{2V_0}{W}$

$x_n = W\frac{N_a}{N_a + N_d}$ $\quad x_p = W\frac{N_d}{N_a + N_d}$

junction cap.	storage charge cap.
due to dipole	diffusion charge p_n, n_p
$C_j = \left\lvert\frac{dQ}{dV_R}\right\rvert = \frac{\varepsilon_s A}{W}$	$C_s, Q_p = qA\int_0^\infty \delta p_n dx_n$
reverse-biased	forward-biased



minimizing the reverse-bias current and the power losses under forward bias

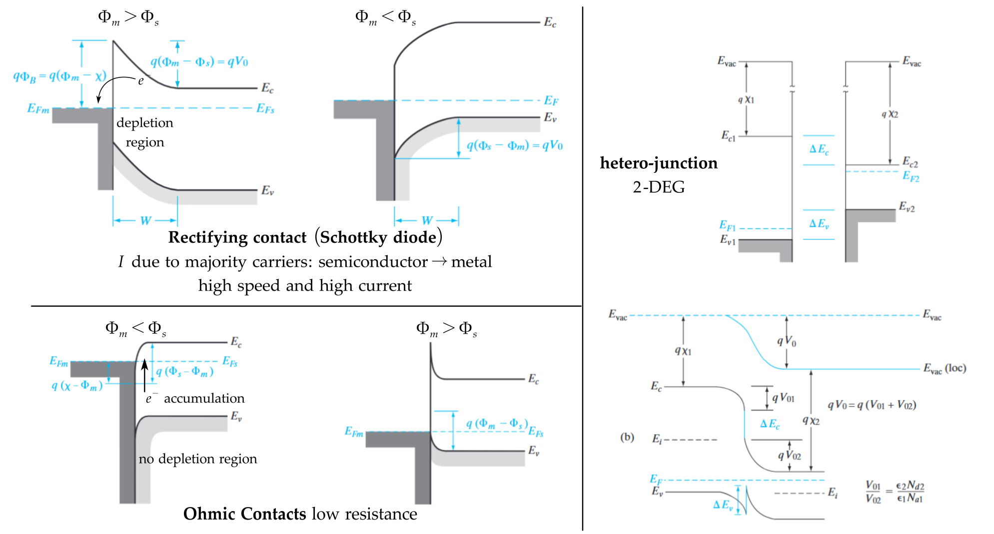
breakdown	Zener: heavily-doped, low V, tunnelling	
	Avalanche: higher V, EHP multiplication, drift in SCR; $V_B = \frac{\varepsilon_s E_{crit}^2}{2eN_d}$	
transient/ac	$i_c(t) = \frac{Q_p}{\tau_p} + \frac{dQ_p}{dt}, Q_p(t) = I_F\tau_p e^{-t/\tau_p}$	improve switching speed: adding recombination centers to the bulk; narrow base diode ($x_n < L_p$)
	$v(t) = \frac{kT}{q}\ln\left(\frac{Q_p(t)}{qAL_p p_n} + 1\right)$	

5.5.5 varactor diode

ohmic loss: For lightly doped, long diodes, resistivity of each neutral region is so high that voltage drops outside the depletion region cannot be neglected. The effects are complicated by the fact that the voltage drop depends on the current.

$V = V_a - I(R_p(I) + R_n(I))$

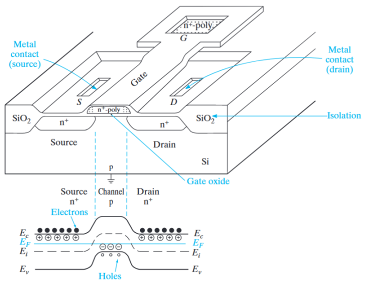
metal-semiconductor junction

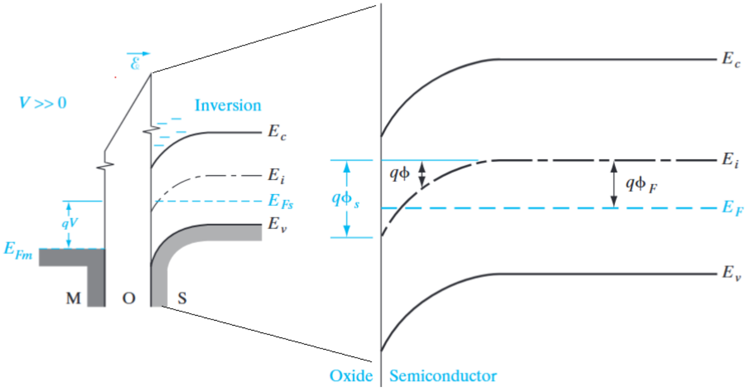


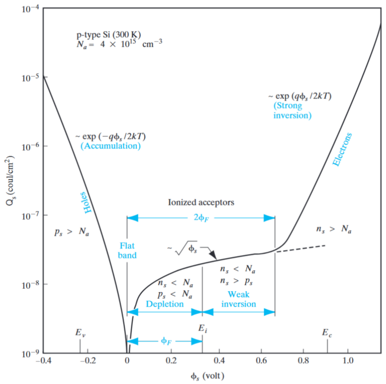
FET

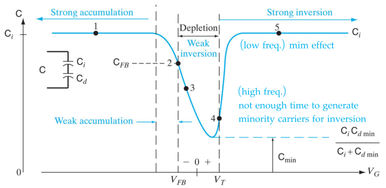
JFET	$G_0 = \frac{2aZ}{\rho L}$	$I_D = G_0 V_P \left(\frac{V_D}{V_P} + \frac{2}{3}\left(-\frac{V_G}{V_P}\right)^{3/2} - \frac{2}{3}\left(\frac{V_D - V_G}{V_P}\right)^{3/2} \right)$
	V_G neg. (sat.)	$V_P = \frac{qa^2 N_d}{2\varepsilon} = -V_{GD}(\text{pinch-off}) + V_0$
MESFET	high speed	HEMT
MOSFET	$f_T = \frac{\mu_n V_{od}}{2\pi L^2}$	$I_D = \frac{\bar{\mu}_n Z C_i}{L}((V_G - V_T)V_D - \frac{1}{2}V_D^2)$

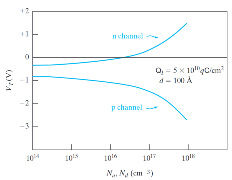
insulator cap.	$C_i(C_{ox}) = \frac{\varepsilon_i}{d}$
eff. interface charge	Q_i
depletion-layer cap.	$C_d = \frac{\varepsilon_s}{W_{\max}}$
depletion width for n^+p	$W = \sqrt{\frac{2\varepsilon_s \phi_s}{qN_a}} \leq 2\sqrt{\frac{\varepsilon_s \phi_F}{qN_a}}$
depletion region charge (SI)	$Q_d = qN_a W_{\max}$
total capacitance	$C_{\min} = \frac{C_i C_d}{C_i + C_d}$
flatband voltage	$V_{FB} = \Phi_{ms} - \frac{Q_i}{C_i}$
mobile ion content	$Q_m = C_i(V_{FB}^- - V_{FB}^+)$
debye screen length, cap.	$C_{debye} = \frac{\varepsilon_s}{L_D} = \sqrt{\frac{\varepsilon_s q^2 N_a}{kT}}$
	$C_{FB} = \frac{C_i C_{debye}}{C_i + C_{debye}}$











	flat-band condition V_{FB}		charge accommodation in depletion region	inversion
$V_T =$	Φ_{ms}	$-\frac{Q_i}{C_i}$	$-\frac{Q_d}{C_i}$	$+2\phi_F$
	$(-)$	$(-)$	$(+)$ n channel $(-)$ p channel	$(+)$ n channel $(-)$ p channel

channel length modulation	$L_{\text{eff}} = L - \Delta L_{dp}(D)$
substrate bias	$\Delta V_T = \frac{\sqrt{2\varepsilon_s q N_a}}{C_i}(\sqrt{2\phi_F - V_B} - \sqrt{2\phi_F})$
sub-threshold	$I_D \propto (1 - e^{-qV_D/kT})e^{qV_{od}/c_r kT}$
short channel, narrow width	D&G shares Q, $L \downarrow \to V_T \downarrow, Z \downarrow \to V_T \uparrow$
gate-induced drain leakage	
drain-induced barrier lowering	before tunnelling, $I_D \uparrow$
punch-through	$DIBL \to$ DS leakage/breakdown, uncontrolled by G
gate oxide breakdown	
hot-electron	$V_T \uparrow, g_m \downarrow$

self-aligned for gate: gate as the mask for implantation of S/D

LOCal Oxidation on Si: nitride mask on gate oxide, wet oxidation, thick field oxide

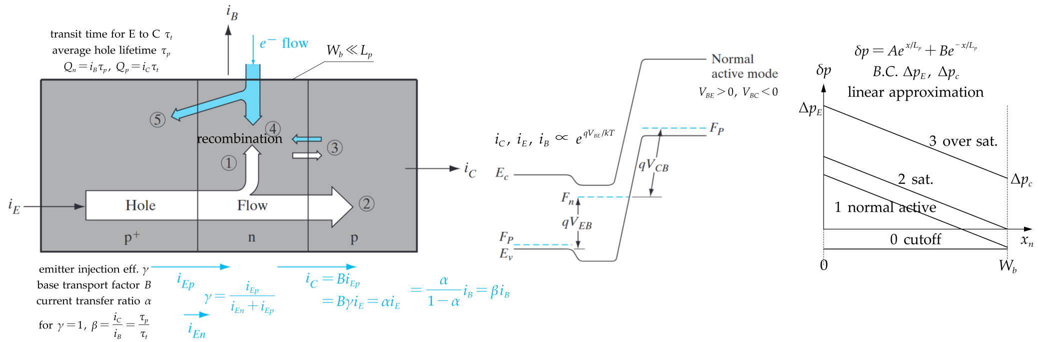
high k: gate oxide
low k: field oxide (isolation)

control V_T: gate electrode, C_i, ion implantation (enhancement/depletion)

For n-type, enhancement mode: 'normally off' with zero gate voltage, $V_T > 0$
depletion mode: 'normally on' with zero gate voltage, $V_T < 0$

Lightly Doped Drain: only needed for n-channel (hot carrier; holes on valence band, low mobility)

BJT



$B = \text{sech}\frac{W_b}{L_p} \approx (1 + \frac{1}{2}\left(\frac{W_b}{L_p^n}\right)^2)^{-1}$	reduce recombination: small n doping & short base width
$\gamma \approx \left(1 + \frac{n_n^B \mu_n^p W_b}{p_p^E \mu_p^n L_n^p}\right)^{-1}$	$\frac{n_p^E}{p_n^B} = \frac{n_n^B}{p_p^E}$; doping E much higher than B, hetero $E_g(E) > E_g(B)$
$f_T = \frac{1}{2\pi\tau_t}$	
Early effect	B-C junction extends into B, $W_b \downarrow, I_C = \frac{1}{r_o}(V_{CE} + V_A)$
current crowding	at emitter edges; smaller W_b, lighter doping in B
Kirk effect	high injection of h^+ into E, $W_b \uparrow, \tau_t \uparrow, I_C \downarrow$ at high

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