

$$\Gamma(r) = \sum \Gamma(K_n) e^{iK_n \cdot r}$$

$$\text{倒格矢: } b_1 = \frac{2\pi[a_2 \times a_3]}{\Omega} \quad b_2 = \frac{2\pi[a_1 \times a_3]}{\Omega} \quad b_3 = \frac{2\pi[a_1 \times a_2]}{\Omega}$$

单电子近似电子的势函数是只关于 \mathbf{r} 的函数

$$\text{德布罗意: } P = \frac{h}{\lambda}$$

$$\text{量子牛顿方程: } \mathbf{f} = \hbar \frac{d\mathbf{k}}{dt} = \frac{d\mathbf{p}}{dt}$$

$$\text{有效质量: } \frac{1}{\hbar^2} \left(\frac{d^2 E}{dk^2} \right)_{k=0} = \frac{1}{m_n^*}$$

$$\text{电子速度: } v = \frac{\hbar k}{m_n^*}$$

E 到 $E+dE$ 之间被电子占据的量子态 $f(E)g(E)dE$

$$\text{导带有效能态密度: } N_c = 2 \left(\frac{m_n^* k_0 T}{2\pi \hbar^2} \right)^{\frac{3}{2}} \quad N_v = 2 \left(\frac{m_p^* k_0 T}{2\pi \hbar^2} \right)^{\frac{3}{2}}$$

$$p = N_v \exp\left(\frac{E_v - E_F}{k_0 T}\right) \quad n = N_c \exp\left(-\frac{E_c - E_F}{k_0 T}\right)$$

$$\text{质量作用定律: } np = N_c N_v \exp\left(-\frac{E_c - E_v}{k_0 T}\right) = N_c N_v \exp\left(-\frac{E_g}{k_0 T}\right) = n_i^2$$

$$\text{本征半导体: } E_i = E_F = \frac{E_c + E_v}{2} + \frac{k_0 T}{2} \ln \frac{N_v}{N_c} = \frac{E_c + E_v}{2} + \frac{3k_0 T}{4} \ln \frac{m_p^*}{m_n^*}$$

可借助质量作用定律推得:

$$n = n_i \exp\left(\frac{E_F - E_i}{k_0 T}\right) \quad p = n_i \exp\left(\frac{E_i - E_F}{k_0 T}\right)$$

$$\text{电中性方程: } \rho = q(N_D + p - n - N_A - n_D + p_A)$$

$$\text{由电中性方程与质量作用定理} \rightarrow n = \frac{N_D}{2} \left[1 + \sqrt{1 + (4n_i^2 / N_D^2)} \right]$$

$$\text{杂质饱和电离: } E_F = E_c + k_0 T \ln\left(\frac{N_D}{N_c}\right) \quad E_F = E_i + k_0 T \ln\left(\frac{N_D}{n_i}\right)$$

简并半导体判断条件:

$$\begin{cases} E_c - E_F > 3k_0 T, \text{ 非简并} \\ 0 < E_c - E_F < 3k_0 T, \text{ 弱简并} \\ E_c - E_F < 0, \text{ 简并} \end{cases}$$

$$\text{简并半导体: } N_D = 0.68 N_c [1 + 2 \exp(\frac{\Delta E_D}{k_0 T})]$$

$$\text{电离杂质散射: } P_i \propto N_i T^{-\frac{3}{2}}$$

$$\text{长纵声学波: } P_s \propto T^{\frac{3}{2}}$$

$$\text{均匀导体的电流密度: } J = \frac{I}{s} = \frac{V}{Rs} = \frac{l|E|}{Rs} = \sigma |E|$$

$$\text{平均迁移率: } \mu = \frac{q\tau}{m_n^*}$$

$$\sigma = nq\mu_n + pq\mu_p$$

迁移率: $\mu = \frac{q}{m^*} \frac{1}{AT^{\frac{3}{2}} + BN_i T^{-\frac{3}{2}}}$

对于n型半导体温度不太高时 $R_H \approx -\frac{1}{nq}$

霍尔效应: 对于p型半导体温度不太高时 $R_H \approx \frac{1}{pq}$

本征情况 $R_H \approx \frac{1-b^2}{n_i q(1+b)^2}$

非子复合: $U = R - G \quad R = rnp \quad G = R_0 = rn_0p_0$

直接复合: $\tau = \frac{\Delta p}{U_d} = \frac{1}{r[(n_0+p_0)+\Delta p]}$

俘获和发射电子能力联系: $s_n = r_n n_1 \quad n_1 = N_c \exp(-\frac{E_c - E_t}{k_0 T})$

通过复合中心复合:

$$U = \frac{N_t r_n r_p (np - n_i^2)}{r_n(n+n_1) + r_p(p+p_1)} = \frac{(np - n_i^2)}{\tau_p(n+n_1) + \tau_n(p+p_1)} \quad \tau = \frac{\Delta p}{U} = \frac{r_n(n_0+n_1+\Delta p) + r_p(p_0+p_1+\Delta p)}{N_t r_n r_p (n_0+p_0+\Delta p)}$$

ps: 可以通过 $n_t = \frac{N_t(r_n n + r_p p_1)}{r_n(n+n_1) + r_p(p+p_1)}$ 推得 另外书上和ppt中的公式是错的

肖克利-瑞德公式:

$$\tau = \frac{\Delta p}{U} = \tau_p \frac{n_0+n_1}{n_0+p_0} + \tau_n \frac{p_0+p_1}{n_0+p_0} \quad \tau = \tau_p = \frac{1}{N_t r_p} \quad \tau = \tau_n = \frac{1}{N_t r_n}$$

能级上电子积累: $\Delta n_t = \frac{N_t n_1}{(n_0+n_1)^2} \Delta n \quad (\Delta n_t)_{max} = \frac{N_t}{4n_0} \Delta n$

一维扩散方程: $\frac{\partial \Delta p(x)}{\partial t} = D_p \frac{d^2 \Delta p(x)}{dx^2} - \frac{\Delta p(x)}{\tau}$

一维稳态扩散方程: $-\frac{dS_p(x)}{dx} = D_p \frac{d^2 \Delta p(x)}{dx^2} = \frac{\Delta p(x)}{\tau_p}$

表明非平衡载流子浓度从光照表面向内部按指数衰减: $\Delta p(x) = (\Delta p)_0 e^{-x/L_p}$

爱因斯坦关系式: $\frac{D}{\mu} = \frac{kT}{q}$

连续性方程: $\frac{\partial p}{\partial t} = D_p \frac{\partial^2 p}{\partial x^2} - \mu_p |E| \frac{\partial p}{\partial x} - \mu_p p \frac{\partial |E|}{\partial x} + g_p - \frac{\Delta p}{\tau_p}$

线性缓变结: $N_D - N_A = \alpha_j(x - x_j)$

突变结接触电势差: $qV_D = E_{Fn} - E_{Fp} \quad V_D = \frac{kT}{q} \ln(\frac{N_A N_D}{n_i^2})$

P-N结载流子分布:

$$p(x) = n_i e^{\frac{E_i(x) - E_F}{kT}} = p_{P0} e^{\frac{E_F - E_i(x_p)}{kT}} e^{\frac{E_i(x) - E_F}{kT}} = p_{P0} e^{\frac{-qV(x)}{kT}} = p_{N0} e^{\frac{qV_D - qV(x)}{kT}}$$

$$n(x) = n_i e^{\frac{E_F - E_i(x)}{kT}} = n_{N0} e^{\frac{E_i(x_n) - E_F}{kT}} e^{\frac{E_F - E_i(x)}{kT}} = n_{N0} e^{\frac{qV(x) - qV_D}{kT}} = n_{P0} e^{\frac{qV(x)}{kT}}$$

$\mathbf{P}^+ \mathbf{N} (N_A \gg N_D) \quad X_D = \sqrt{\frac{2\epsilon_r \epsilon_0 V_D}{qN_D}} \rightarrow X_D \approx x_n \quad \mathbf{N}^+ \mathbf{P} \text{ 结 } (N_D \gg N_A) \quad X_D =$

线性缓变结: $X_D = \left(\frac{12\epsilon_r \epsilon_0 V_D}{q\alpha} \right)^{1/3}$

正偏压P-N结:

$$\Delta n(x) = \Delta n(-x_p) \exp\left(\frac{x+x_p}{L_n}\right) \quad \Delta p(x) = \Delta p(x_n) \exp\left(-\frac{x-x_n}{L_p}\right)$$

反偏压P-N结: $\Delta n(x) = -n_{p0} \exp\left(\frac{x+x_p}{L_n}\right) \quad \Delta p(x) = -p_{n0} \exp\left(-\frac{x-x_n}{L_p}\right)$

理想P-N结I-V特性:

$$J = J_s \left[\exp\left(\frac{qV}{kT}\right) - 1 \right] \quad J_s = \left(\frac{qD_p n_i^2}{L_p N_D} + \frac{qD_n n_i^2}{L_n N_A} \right) \text{反偏饱和电流密度}$$

理想P-N结I-V特性修正:

正向偏压:

$$\frac{J_{fd}}{J_r} \propto \frac{2n_i L_p}{N_D X_D} \exp(qV/2kT) \quad J_{fd} \text{为扩散电流密度} \quad J_r \text{为正偏复合电流密度}$$

反向偏压:

$$J_G = qGX_D = q\frac{n_i}{2\tau} X_D \quad J_G \text{产生电流密度}$$

$$\frac{J_{rd}}{J_G} = 2 \frac{n_i}{N_D} \frac{L_p}{X_D}$$

$$\text{平行板电容: } C_T = \frac{A\epsilon_0\epsilon_r}{X_D}$$

$$\text{泊松方程: } \frac{d^2V}{dx^2} = -\frac{\rho(x)}{\epsilon_r\epsilon_0}$$

$$\text{肖特基二极管空间电荷区宽: } d = \left[\frac{2\epsilon_0\epsilon_r}{qN_D} (\phi_{ns} - \phi_n) \right]^{1/2} = \left(\frac{2\epsilon_0\epsilon_r}{qN_D} V_D \right)^{1/2}$$

适用于势垒宽度>>电子平均自由程:

$$J = J_{SD} [\exp(qV/kT) - 1] \quad J_{SD} = \frac{q^2 D_n n_0}{kT} \left[\frac{2qN_D}{\epsilon_0\epsilon_r} (V_D - V) \right]^{1/2} \exp\left(\frac{-qV_D}{kT}\right)$$

表面空间电荷层的电场:

$$E^2(x) = \left(\frac{2kT}{q} \right)^2 \left(\frac{q^2 p_{p0}}{2\epsilon_s kT} \right) \left\{ \left[\exp\left(-\frac{qV}{kT}\right) + \frac{qV}{kT} - 1 \right] + \frac{n_{p0}}{p_{p0}} \left[\exp\left(\frac{qV}{kT}\right) - \frac{qV}{kT} - 1 \right] \right\}$$

$$E(x) = \pm \frac{2kT}{qL_D} F\left(\frac{qV(x)}{kT}, \frac{n_{p0}}{p_{p0}}\right) \quad L_D = \left(\frac{2\epsilon_s kT}{q^2 p_{p0}} \right)^{1/2}$$

$$\text{高斯原理: } Q_s = -\epsilon_s E_s$$

耗尽层宽度最大值:

$$d_{\max} = \left(\frac{2\epsilon_s}{q} \frac{2V_B}{N_A} \right)^{1/2} \text{外加电场被反型层屏蔽, 耗尽层宽度达到最大}$$

$$C_s = \left| \frac{dQ_s}{dV_s} \right| = \frac{\epsilon_s}{L_D} \left\{ \left[-\exp\left(-\frac{qV_s}{kT}\right) + 1 \right] + \frac{n_{p0}}{p_{p0}} \left[\exp\left(\frac{qV_s}{kT}\right) - 1 \right] \right\} / F\left(\frac{qV_s}{kT}, \frac{n_{p0}}{p_{p0}}\right)$$

$$\text{绝缘层单位面积电容: } C_{ox} = \frac{\epsilon_{ox}}{d_{ox}}$$

平带电容:

$$C_{FBS} = \lim_{V_s \rightarrow 0} \frac{dQ_s}{dV_s} = \frac{\sqrt{2}\epsilon_s}{L_D} \left(1 + \frac{n_{p0}}{p_{p0}} \right)^{1/2} \approx \frac{\sqrt{2}\epsilon_s}{L_D} \quad C_{FB} = C_{ox} / 1 + \frac{\epsilon_{ox}}{d_{ox}} \left(\frac{kT}{q^2 N_A \epsilon_s} \right)^{1/2}$$

$$\text{高频情况反型层电子产生复合更不上高频信号的变化: } \frac{C'_{\min}}{C_{ox}} = \frac{1}{1 + \frac{4\epsilon_s kT}{e_s} \ln\left(\frac{N_A}{n_i}\right)^{1/2}}$$

$$\text{阈值电压: } V_T = \phi_{ms} - \frac{Q_{ox}}{C_{ox}} - \frac{Q_B}{C_{ox}} + 2\phi_F$$

$$V_{Tn} = -V_{ms} - \frac{Q_{ox}}{C_{ox}} + \frac{qN_D x_{d\max}}{C_{ox}} + \frac{2kT}{q} \ln \frac{N_A}{n_i}$$

$$V_{Tp} = -V_{ms} - \frac{Q_{ox}}{C_{ox}} - \frac{qN_D x_{d\max}}{C_{ox}} - \frac{2kT}{q} \ln \frac{N_D}{n_i}$$

反型层电荷: $Q_n(y) = -C_{ox} [V_{GS} - V(y) - V_T]$

萨支唐方程: $I_{DS} = \beta [(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^2] \quad \beta \equiv \frac{\mu_n W C_{ox}}{L}$

沟道夹断: $I_{DSat} = \frac{\beta}{2}(V_{GS} - V_T)^2 \quad V_{DSat} \equiv V_{GS} - V_T$