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

倒格矢: 
$$b_1=rac{2\pi[a_2 imes a_3]}{\Omega}$$
  $b_2=rac{2\pi[a_1 imes a_3]}{\Omega}$   $b_3=rac{2\pi[a_1 imes a_2]}{\Omega}$ 

单电子近似电子的势函数是只关于r的函数

德布罗意:  $P = \frac{h}{\lambda}$ 

量子牛顿方程:  $f = \hbar \frac{dk}{dt} = \frac{dp}{dt}$ 

有效质量: 
$$\frac{1}{\hbar^2} \left( \frac{\mathbf{d}^2 E}{\mathbf{d} k^2} \right)_{k=0} = \frac{1}{m_\mathrm{n}^*}$$

电子速度: $v=rac{\hbar k}{m_n*}$ 

E 到E+dE 之间被电子占据的量子态f(E)g(E)dE

导带有效能态密度: 
$$N_c=2(rac{m_n^*k_0T}{2\pi\hbar^2})^{rac{3}{2}}$$
  $N_
u=2(rac{m_p^*k_0T}{2\pi\hbar^2})^{rac{3}{2}}$ 

$$p = N_
u exp(rac{E_v - E_F}{k_0 T})$$
  $n = N_c exp(-rac{E_c - E_F}{k_0 T})$ 

质量作用定律: 
$$np=N_cN_
u\exp(-rac{E_c-E_
u}{k_0T})=N_cN_
u\exp(-rac{E_g}{k_0T})=n_i^2$$

本征半导体: 
$$E_i=E_F=rac{E_c+E_
u}{2}+rac{k_0T}{2}\lnrac{N_
u}{N_c}=rac{E_c+E_
u}{2}+rac{3k_0T}{4}\lnrac{m_p^*}{m_n^*}$$

可借助质量作用定律推得:

$$n=n_i \exp(rac{E_F-E_i}{k_0T})$$
  $p=n_i \exp(rac{E_i-E_F}{k_0T})$ 

电中性方程: 
$$ho = q\left(N_D + p - n - N_A - n_D + p_A
ight)$$

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

杂志饱和电离: 
$$E_F=E_c+k_0T\ln(rac{N_D}{N_C})$$
  $E_F=E_{
m i}+k_0T\ln(rac{N_D}{n_i})$ 

简并半导体判断条件:

$$\left\{egin{aligned} E_c - E_F > 3k_0T, 非简并 \ 0 < E_c - E_F < 3k_0T, 弱简并 \ E_c - E_F < 0, 简并 \end{aligned}
ight.$$

简并半导体:  $N_D=0.68N_c[1+2\exp(rac{ riangle E_D}{k_0T})]$ 

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

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

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

平均迁移率:  $\mu = \frac{q \tau}{m^*}$ 

 $\sigma = nq\mu_{
m n} + pq\mu_{
m p}$ 

迁移率:  $\mu = \frac{q}{m^*} \frac{1}{4T^{\frac{3}{2}} + RN \cdot T^{-\frac{3}{2}}}$ 

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
$$R_H pprox rac{1-b^2}{n_i q(1+b)^2}$$

非子复合: U=R-G R=rnp  $G=R_0=rn_0p_0$ 

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

俘获和发射电子能力联系:  $s_n = r_{
m n} n_1$   $n_1 = N_c \exp(-\frac{E_c - E_t}{k_o T})$ 

## 通过复合中心复合:

$$U = rac{N_t r_n r_p (np - n_i^2)}{r_n (n + n_1) + r_p (p + p_1)} = rac{(np - n_i^2)}{ au_p (n + n_1) + au_n (p + p_1)} \quad au = rac{\Delta p}{U} = rac{r_n (n_0 + n_1 + \Delta p) + r_p (p_0 + p_1 + \Delta p)}{N_t r_n r_p (n_0 + p_0 + \Delta p)}$$

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

## 肖克利-瑞德公式:

$$au = rac{\Delta p}{U} = au_p rac{n_0 + n_1}{n_0 + p_0} + au_n rac{p_0 + p_1}{n_0 + p_0} \quad au = au_p = rac{1}{N_t r_p} \quad au = au_n = rac{1}{N_t r_n}$$

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

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

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

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:  $\frac{D}{\mu} = \frac{kT}{g}$ 

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

线性缓变结:  $N_D - N_A = \alpha_i(x - x_i)$ 

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

## P-N结载流子分布:

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

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

$$\mathbf{P}^{+}\mathbf{N}\left(N_{A}\gg\ N_{D}
ight) \quad X_{D}=\sqrt{rac{2arepsilon_{r}arepsilon_{0}V_{D}}{qN_{D}}}$$
  $\longrightarrow X_{D}pprox x_{n}$   $\mathbf{N}^{+}\mathbf{P}$ 结 $\left(N_{D}\gg N_{A}
ight) \quad X_{D}=$ 

线性缓变结:  $X_D = \left(\frac{12\varepsilon_r \varepsilon 0 V_D}{q lpha}\right) 1/3$ 

## 正偏压P-N结:

$$\Delta n(x) = \Delta n(-x_p) \exp\left(rac{x+x_p}{L_n}
ight) \quad \Delta p(x) = \Delta p(x_n) \exp\left(-rac{x-x_n}{L_n}
ight)$$

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

理想P-N结I-V特件:

$$J=J_sigg[\expigg(rac{qV}{kT}igg)-1igg]$$
  $J_s=igg(rac{qD_pn_i^2}{L_pN_D}+rac{qD_nn_i^2}{L_nN_A}igg)$ 反偏饱和电流密度

理想P-N结I-V特性修正:

正向偏压:

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

反向偏压:

$$J_G = qGX_D = qrac{n_i}{2 au}X_D$$
  $J_G$ 产生电流密度 $rac{J_{rd}}{J_G} = 2rac{n_i}{N_D}rac{L_p}{X_D}$ 

平行板电容:  $C_T = \frac{A\varepsilon_0\varepsilon_r}{X_D}$ 泊松方程:  $\frac{d^2V}{dx^2} = -\frac{\rho(x)}{\varepsilon_0\varepsilon_0}$ 

肖特基二极管空间电荷区宽:  $d=\left[rac{2arepsilon_0arepsilon_r}{qN_D}(\phi_{ns}-\phi_n)
ight]^{1/2}=\left(rac{2arepsilon_0arepsilon_r}{qN_D}V_D
ight)^{1/2}$ 

适用于势垒宽度>>电子平均自由程:

$$J=J_{_{SD}}[\exp(qV/kT)-1]$$
  $J_{_{SD}}=rac{q^2D_nn_0}{kT}[rac{2qN_D}{arepsilon_0arepsilon_c}(V_D-V)]^{rac{1}{2}}\exp(rac{-qV_D}{kT})$ 

表面空间电荷层的电场:

$$E^2(x) = \left(rac{2kT}{q}
ight)^2 \left(rac{q^2p_{p0}}{2arepsilon_s kT}
ight) \left\{ \left[\exp\left(-rac{qV}{kT}
ight) + rac{qV}{kT} - 1
ight] + rac{n_{p0}}{p_{p0}} \left[\exp\left(rac{qV}{kT}
ight) - rac{qV}{kT} - 1
ight] 
ight\} \ E(x) = \pm rac{2kT}{qL_D} F\left(rac{qV(x)}{kT}, rac{n_{p0}}{p_{p0}}
ight) \quad L_D = \left(rac{2arepsilon_s KT}{q^2p_{p0}}
ight)^{1/2}$$

高斯原理:  $Q_s = -\varepsilon_s E_s$ 

耗尽层宽度最大值:

$$d_{\max} = \left(rac{2arepsilon_s}{q}rac{2V_B}{N_A}
ight)^{1/2}$$
外加电场被反型层屏蔽,耗尽层宽度达到最大  $C_s = \left|rac{dQ_s}{dV_s}
ight| = rac{arepsilon_s}{L_D} \left\{\left[-\exp\left(-rac{qV_s}{kT}
ight) + 1
ight] + rac{n_{p0}}{p_{p0}} \left[\exp\left(rac{qV_s}{kT}
ight) - 1
ight]
ight\}/F\left(rac{qV_s}{kT}, rac{n_{p0}}{p_{p0}}
ight)$  绝缘层单位面积电容: $C_{ox} = rac{\mathcal{E}_{ox}}{d_{ox}}$ 

平带电容:

$$C_{FBS} = \lim_{V_s o 0} rac{dQ_s}{dV_s} = rac{\sqrt{2}arepsilon_s}{L_D} \left(1 + rac{n_{p0}}{p_{p0}}
ight)^{1/2} pprox rac{\sqrt{2}arepsilon_s}{L_D} \quad C_{_{FB}} = C_{_{ox}}/1 + rac{arepsilon_{ox}}{d_{ox}} \left(rac{kT}{q^2N_A oldsymbol{arepsilon}_s}
ight)^{rac{1}{2}}$$

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

阈值电压:
$$V_T = \phi_{ms} - rac{Q_{ox}}{C_{ox}} - rac{Q_B}{C_{ox}} + 2\phi_F$$
 $V_{Tn} = -V_{ms} - rac{Q_{\alpha x}}{C_{\alpha x}} + rac{qN_d x_{d\max}}{C_{ox}} + rac{2kT}{q} \ln rac{N_A}{n_i}$ 
 $V_{Tp} = -V_{ms} - rac{Q_{\alpha x}}{C_{ox}} - rac{qN_D x_{d\max}}{C_{\alpha x}} - rac{2kT}{q} \ln rac{N_D}{n_i}$ 

反型层电荷:  $Q_{n}\left(y\right)=-C_{oX}\left[V_{\scriptscriptstyle GS}-V\left(y\right)-V_{\scriptscriptstyle T}
ight]$ 

萨支唐方程:  $I_{DS}=eta\left[(V_{GS}-V_T)V_{DS}-rac{1}{2}V_{DS}^2
ight]$   $eta\equivrac{\mu_nWC_{ox}}{L}$ 沟道夹断:  $I_{DSat}=rac{eta}{2}(V_{GS}-V_T)^2$   $V_{DSat}\equiv V_{GS}-V_T$