第八章 p-n结

8.1 平衡p-n结特性

8.2 p-n结电流电压特性

8.3 p-n结电容

8.4 p-n结的击穿

8.5 p-n结隧道效应

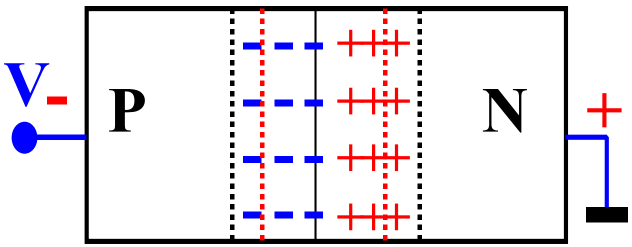
by云墨一点

8.3 p-n结电容1

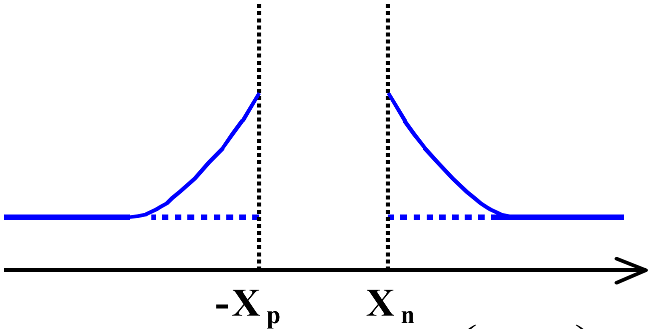
8.3.1 势垒电容

$$C=\frac{dQ}{dV}$$

势垒电容



扩散电容



$$p(x_n)=p_{n0}\exp\left(\frac{qV}{kT}\right)$$

—突变结

$$x_n=\frac{N_A}{N_A+N_D}X_D$$

$$|Q|=AqN_Ax_p=AqN_Dx_n \longrightarrow |Q|=Aq\left[\frac{2\varepsilon_0\varepsilon_r}{q}\frac{N_AN_D}{N_A+N_D}(V_D-V)\right]^{1/2}$$

耗尽层近似→ $X_D=\sqrt{\dfrac{2\varepsilon_r\varepsilon_0(N_A+N_D)(V_D-V)}{qN_AN_D}}$

平行板电容

$$C_T=A\sqrt{\frac{q\varepsilon_r\varepsilon_0N_B}{2(V_D-V)}} \xleftarrow{\text{突变结}} \boxed{\frac{A\varepsilon_0\varepsilon_r}{X_D}}=C_T=\frac{dQ}{dV}=A\left[\frac{\varepsilon_0\varepsilon_r q}{2(V_D-V)}\frac{N_AN_D}{N_A+N_D}\right]^{1/2}$$

N_B：轻掺杂浓度

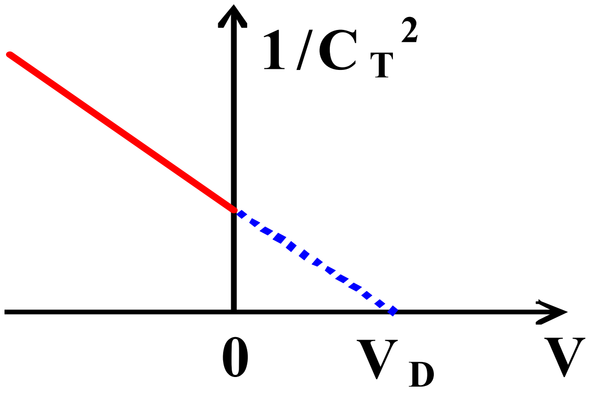
8.3 p-n结电容2

8.3.1 势垒电容

一突变结

轻掺杂浓度

$$C_T = A\sqrt{\frac{q\varepsilon_r\varepsilon_0 \boxed{N_B}}{2(V_D - V)}}$$



耗尽层近似 ⟶ 反向适用

一突变结（正向偏压） $C_T = \frac{dQ}{dV} = A\left[\frac{\varepsilon_0\varepsilon_r q}{2(V_D - V)}\frac{N_A N_D}{N_A + N_D}\right]^{1/2}$

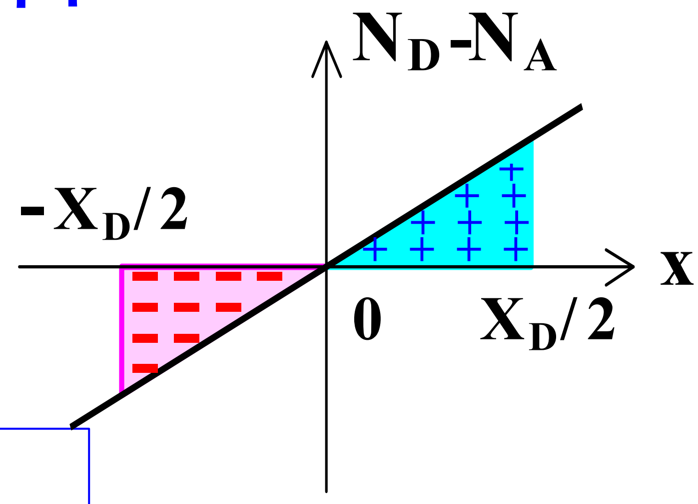
考虑势垒区中的载流子作用

$$C_T = 4C_T(0) = 4A\sqrt{\frac{\varepsilon_r\varepsilon_0 q N_A N_D}{2(N_A + N_D)V_D}}$$

8.3 p-n结电容3

8.3.1 势垒电容

一线性缓变结



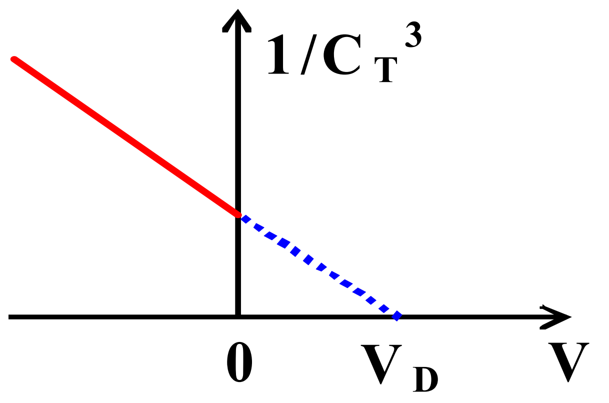
$$|Q|=A\int_0^{X_D/2}\rho(x)dx=A\int_0^{X_D/2}qa_jxdx=A\frac{qa_jX_D^2}{8}$$

$$X_D=\left(\frac{12\varepsilon_r\varepsilon_0(V_D-V)}{qa_j}\right)^{1/3}$$

$$\boxed{Q=A\left(\frac{9qa_j\varepsilon_r^2\varepsilon_0^2}{32}\right)^{\frac{1}{3}}(V_D-V)^{2/3}}$$

$$C_T=\frac{dQ}{dV}=A\left[\frac{q\alpha_j\varepsilon_0^2\varepsilon_r^2}{12(V_D-V)}\right]^{1/3}\boxed{=\frac{A\varepsilon_0\varepsilon_r}{X_D}}$$

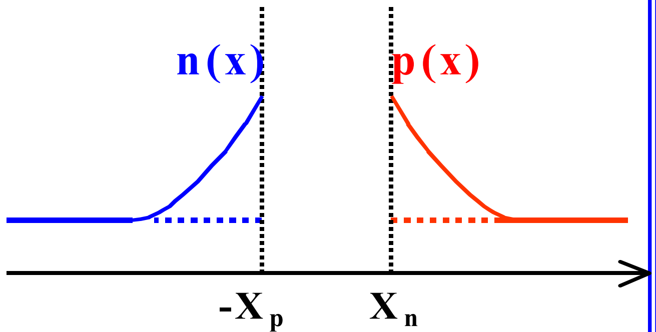
平行板电容



8.3 p-n结电容4

8.3.2 扩散电容 (正向偏压)

N区 $\Delta p(x) = p_{n0}\left[\exp\left(\frac{qV}{kT}\right)-1\right]\exp\left(-\frac{x-x_n}{L_p}\right)$



$$Q_p = Ae\int_{x_n}^{\infty}\Delta p(x)dx = AqL_p p_{n0}\left[\exp\left(\frac{qV}{kT}\right)-1\right]$$

$$\boxed{C_{dp} = \frac{dQ_p}{dV} = A\frac{q^2 L_p p_{n0}}{kT}\exp\left(\frac{qV}{kT}\right)}$$

P区 $\boxed{C_{dn} = A\frac{q^2 L_n n_{p0}}{kT}\exp\left(\frac{qV}{kT}\right)}$

总扩散电容 $Q = Q_p + Q_n$

$$\frac{dQ}{dV} = \frac{dQ_p}{dV} + \frac{dQ_n}{dV} \qquad C_d = C_{dp} + C_{dn}$$

$$\boxed{C_d = \left[Aq^2\frac{(n_{p0}L_n + p_{n0}L_p)}{kT}\right]\exp\left(\frac{qV}{kT}\right)}$$

大的正向偏压下，扩散电容为主

第八章 p-n结

8.1 平衡p-n结特性

8.2 p-n结电流电压特性

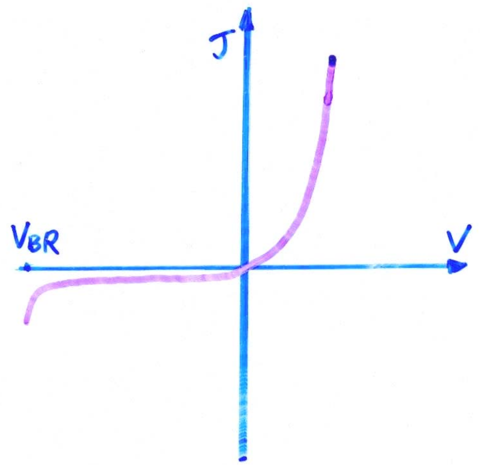
8.3 p-n结电容

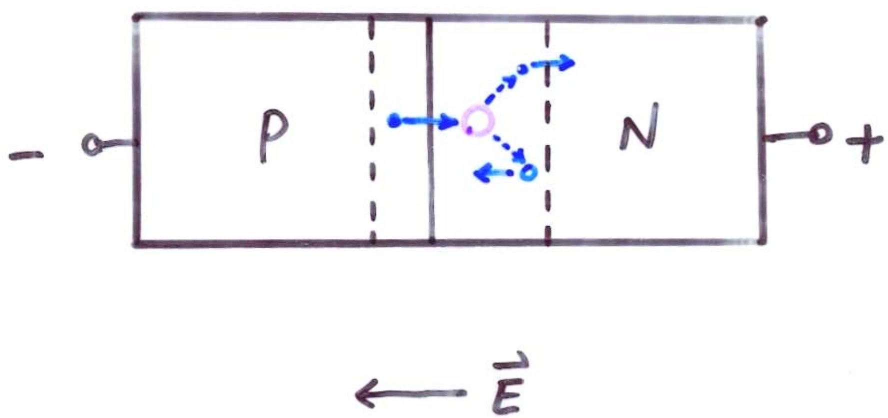
8.4 p-n结的击穿

8.5 p-n结隧道效应

8.4 p-n结的击穿1

8.4.1 雪崩击穿





碰撞离化率 α_n, α_p

— 一个载流子漂移单位距离内产生的电子-空穴对的数目

$$\alpha(E)=\alpha_0\exp\left[-(E_0/E)^m\right]$$

雪崩击穿条件

$$N=\int_0^{x_D}\alpha_n dx=1$$

倍增因子M

$$M=\frac{J}{J_0}=\frac{1}{1-\int_0^{x_D}\alpha_n dx}\to\infty$$

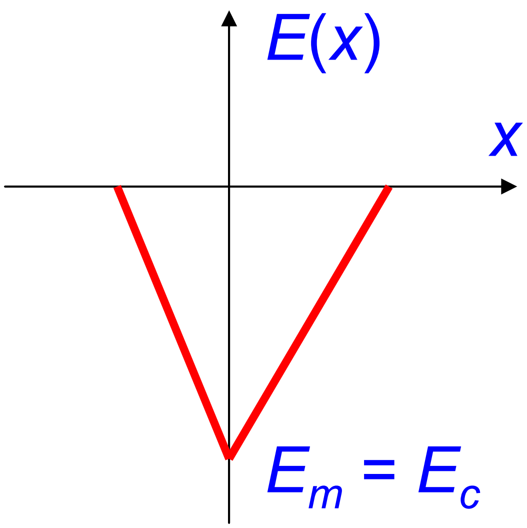
8.4 p-n结的击穿2

8.4.1 雪崩击穿

估算Si p-n结中的击穿电压（$E_c = 2\text{~}5\times10^5$ V/cm)

$$\boxed{X_D = \sqrt{\frac{2\varepsilon_r\varepsilon_0(N_A+N_D)(V_D-V)}{qN_AN_D}}}$$

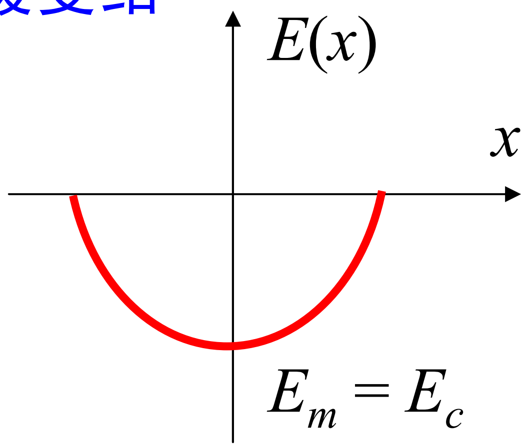
突变结



$$\begin{cases} V_{BR} = \dfrac{1}{2}E_c \cdot X_D \\ X_D = \left(\dfrac{2\varepsilon_0\varepsilon_r}{q}\dfrac{V_{BR}}{N_B}\right)^{1/2} \end{cases}$$

$$\Rightarrow V_{BR} = \frac{\varepsilon_0\varepsilon_r}{2q}\frac{E_c^2}{N_B}$$

线性缓变结

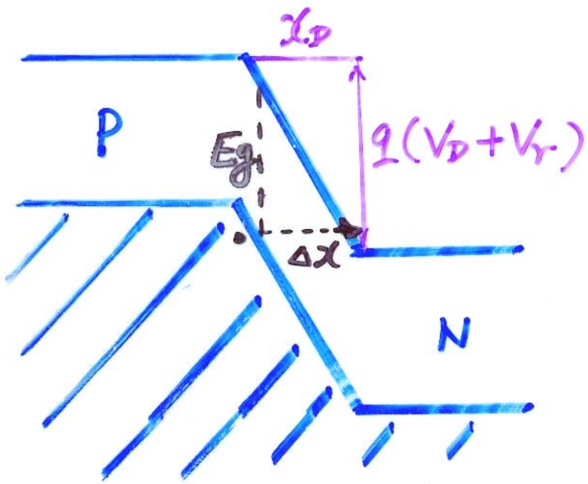


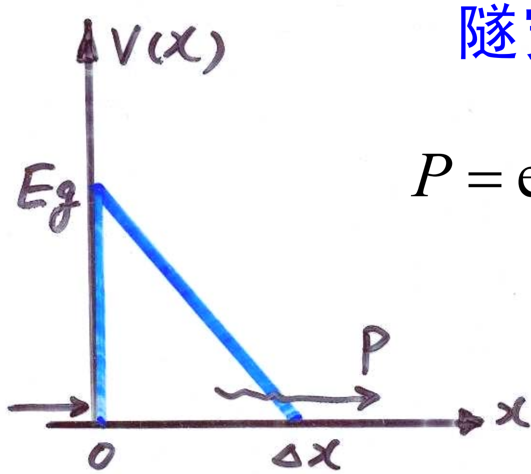
$$V_{BR} = \left(\frac{32\varepsilon_0\varepsilon_r E_c^3}{9\alpha_j q}\right)^{1/2}$$

$T\uparrow \quad l\downarrow \quad V_{BR}\uparrow$ 正温度系数

8.4 p-n结的击穿3

8.4.2 齐纳击穿（隧道击穿）





隧穿几率

$$P = \exp\left[-\frac{8\pi}{3}\left(\frac{2m_n^*}{h^2}\right)^{1/2} E_g^{1/2}\Delta x\right]$$

$$\frac{E_g}{\Delta x} = \frac{q(V_D - V)}{x_D} \longrightarrow \Delta x = \frac{E_g}{q}\left(\frac{2\varepsilon_0\varepsilon_r}{q}\frac{1}{N_{eff}V_A}\right)^{1/2}$$

$$N_{eff} = \frac{N_D N_A}{N_D + N_A}$$

$$V_A = V_D - V$$

$T\uparrow$ $E_g\downarrow$ $P\uparrow$ $V_{BR}\downarrow$ 负温度系数

重掺杂Ge、Si p-n结 V_{BR} $< 4E_g/q$ $> 6E_g/q$

齐纳 雪崩

第八章 p-n结

8.1 平衡p-n结特性

8.2 p-n结电流电压特性

8.3 p-n结电容

8.4 p-n结的击穿

8.5 p-n结隧道效应

by云墨一点

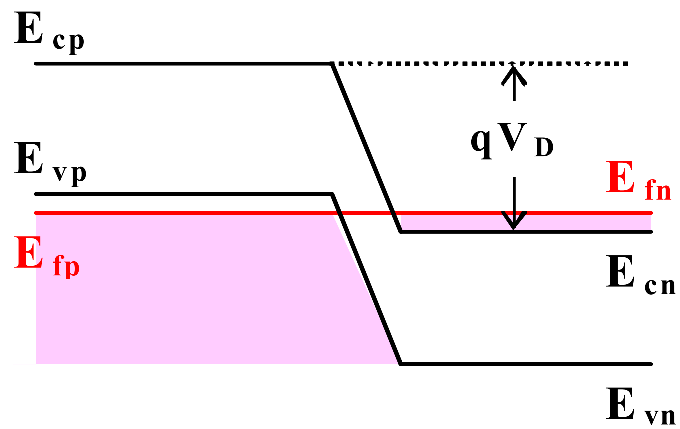
8.5 p-n结隧道效应1

8.5.1 简并P-N结的能带图

简并半导体

$$P: \quad E_{vp} > E_{fp}$$

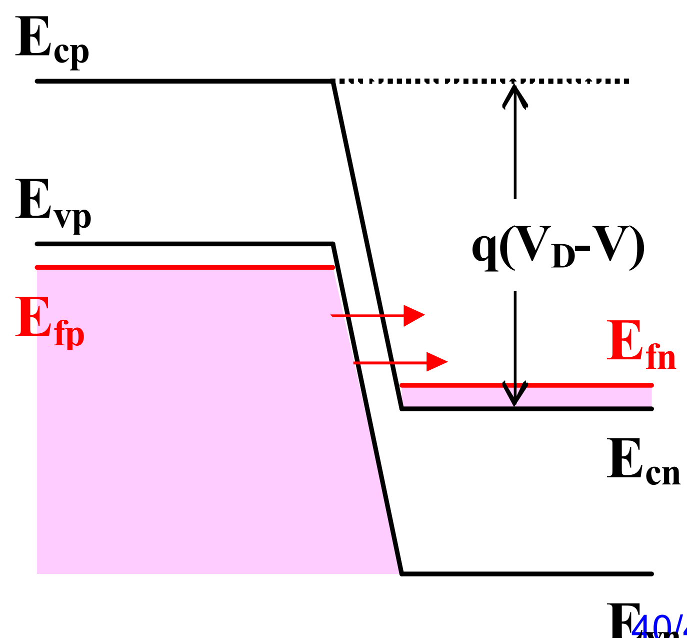
$$N: \quad E_{fn} > E_{cn}$$



简并P-N结

$$V = 0: \quad E_{fp} = E_{fn} \qquad V < 0: \quad E_{fp} > E_{fn}$$

$$E_{vp} > E_{cn}$$



$$X_D = \sqrt{\frac{2\varepsilon_r \varepsilon_0 (N_A + N_D)(V_D - V)}{qN_A N_D}}$$

$N_D=N_A=10^{21}cm^{-3}$, $V_D=1.28eV$

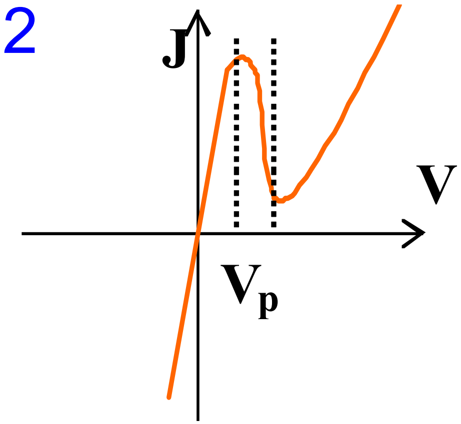
$X_D=0.53nm$

by云墨一点

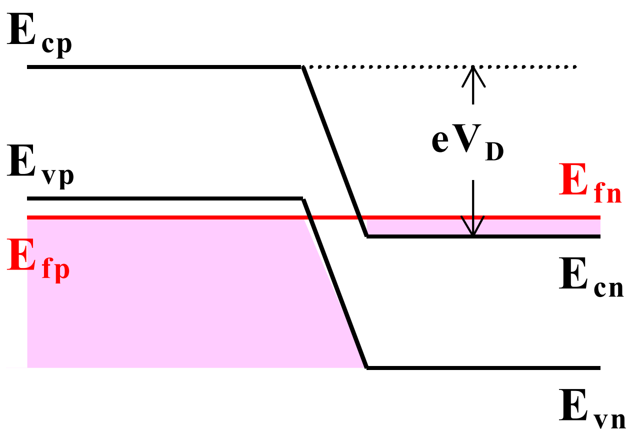
8.5 p-n结隧道效应2

8.5.2 Esaki 二极管

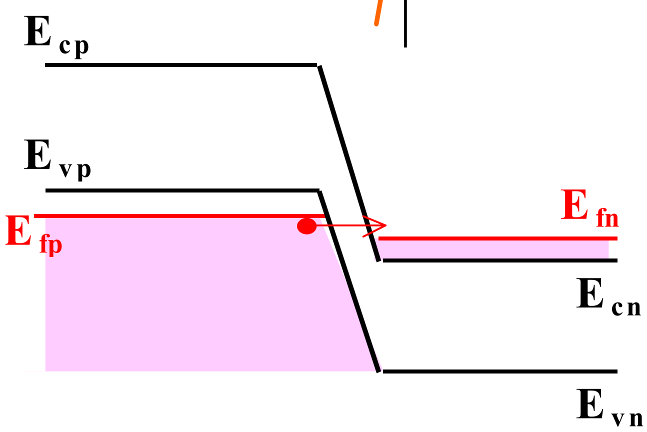
V_p~100-200mV



V=0

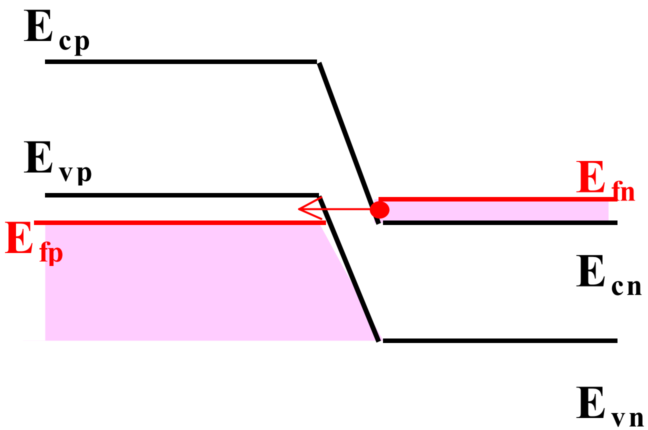


V<0



V>0

V<V_p



V>0

V>V_p