第八章 p-n结

8.2 p-n结电流电压特性1

8.2.1 p-n结中的电场和电势分布

一突变结p+- n

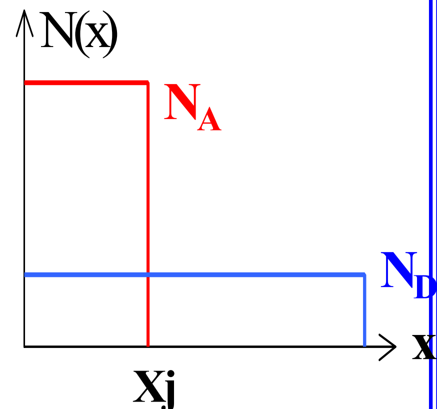
电荷分布

$$\rho(x)=q(N_D-N_A+p-n)$$

$$\rho(x)=-qN_A,\ -x_p\le x\le 0$$

$$\rho(x)=qN_D,\ 0\le x\le x_n$$

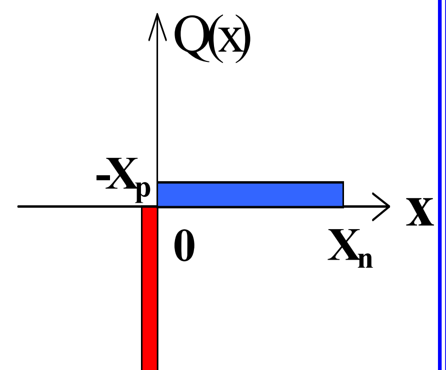
耗尽近似 $\boxed{p,n=0}$



泊松方程

$$\frac{d^2V}{dx^2}=-\frac{\rho(x)}{\varepsilon_r\varepsilon_0}$$

$$E(x)=-\frac{dV(x)}{dx}=-\int\frac{d^2V}{dx^2}dx$$



电场分布

边界条件 $x=x_n, x=-x_p, E=0$

$-x_p\le x\le 0$

$$E(x)=\int\frac{\rho(x)}{\varepsilon_r\varepsilon_0}dx=-\int\frac{qN_A}{\varepsilon_r\varepsilon_0}dx=-\frac{qN_A}{\varepsilon_r\varepsilon_0}x+C \rightarrow \boxed{E_p(x)=-\frac{qN_A}{\varepsilon_r\varepsilon_0}(x+x_p)}$$

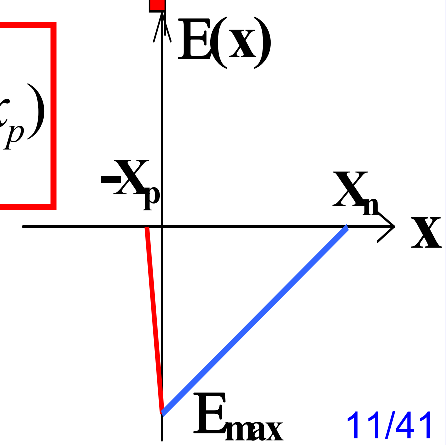
$$C=-\frac{qN_A}{\varepsilon_r\varepsilon_0}x_p$$

$0\le x\le x_n$

$x=0$

$$\boxed{E_n(x)=-\frac{qN_D}{\varepsilon_r\varepsilon_0}(x_n-x)}$$

$$\boxed{E_m=-\frac{qN_Ax_p}{\varepsilon_r\varepsilon_0}=-\frac{qN_Dx_n}{\varepsilon_r\varepsilon_0}}$$



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8.2 p-n结电流电压特性2

8.2.1 p-n结中的电场和电势分布

—突变结p+- n

$$E_m = -\frac{qN_A x_p}{\varepsilon_r \varepsilon_0} = -\frac{qN_D x_n}{\varepsilon_r \varepsilon_0}$$

正负电荷总量相等

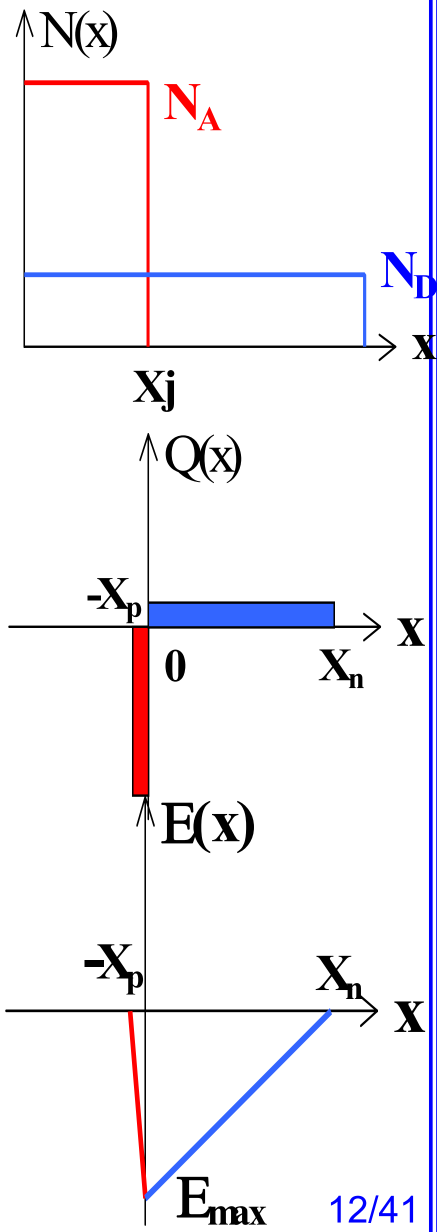
$$\boxed{qN_A x_p = qN_D x_n}$$

$$\boxed{\frac{x_n}{x_p} = \frac{N_A}{N_D}}$$

$$N_A >> N_D$$

$$\boxed{x_n >> x_p}$$

耗尽区主要在轻掺杂区的一边



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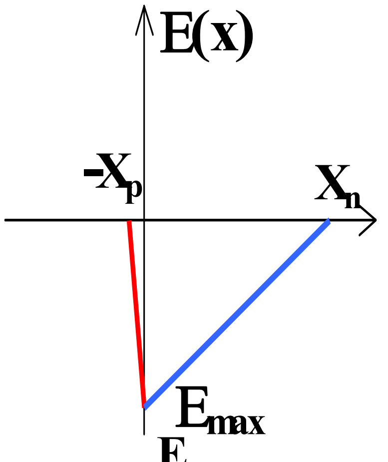
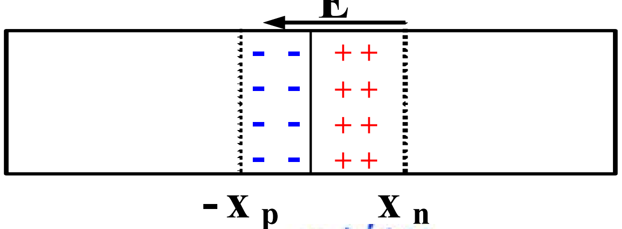
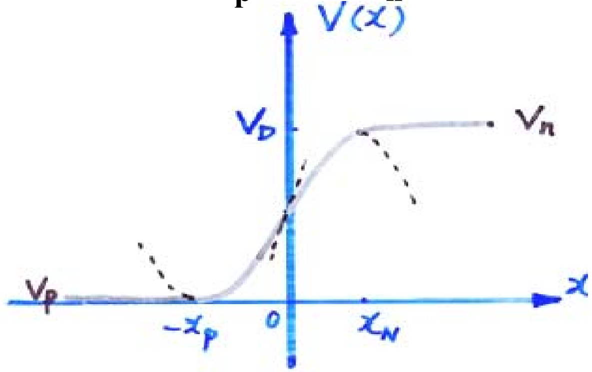
8.2 p-n结电流电压特性3

8.2.1 p-n结中的电场和电势分布

一突变结p+- n







电场分布 $E_p(x)=-\dfrac{qN_A}{\varepsilon_r\varepsilon_0}(x+x_p)$ $E_n(x)=-\dfrac{qN_D}{\varepsilon_r\varepsilon_0}(x_n-x)$

电势分布 $\boxed{V(x)=-\int E(x)dx}$

边界条件 $-x_p\le x\le 0 \quad x=-x_p, V=0$

$0\le x\le x_n \quad x=x_n, V=V_D$

$-x_p\le x\le 0$

$$V(x)=\int\frac{qN_A}{\varepsilon_r\varepsilon_0}(x+x_p)dx=\frac{qN_A}{2\varepsilon_r\varepsilon_0}(x+x_p)^2+C,\ \ \mathrm{C}=0$$

$$\boxed{V_p(x)=\frac{qN_A}{2\varepsilon_r\varepsilon_0}(x+x_p)^2}\qquad \boxed{V_n(x)=V_D-\frac{qN_D}{2\varepsilon_r\varepsilon_0}(x_n-x)^2}$$

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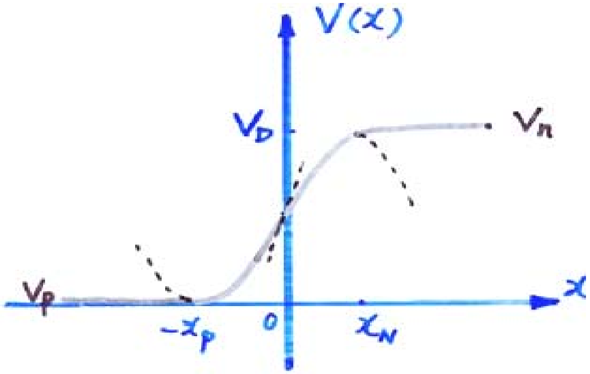
8.2 p-n结电流电压特性4

8.2.1 p-n结中的电场和电势分布

一突变结p+- n 电势分布

$$V_p(x)=\frac{qN_A}{2\varepsilon_r\varepsilon_0}(x+x_p)^2$$

$$V_n(x)=V_D-\frac{qN_D}{2\varepsilon_r\varepsilon_0}(x_n-x)^2$$



$x=0$ $\quad V_p(x)=V_n(x) \rightarrow$

$$V_D=\frac{qN_A}{2\varepsilon_r\varepsilon_0}x_p^2+\frac{qN_D}{2\varepsilon_r\varepsilon_0}x_n^2$$

势垒宽度 $X_D=x_p+x_n$

$$\frac{x_p}{x_n}=\frac{N_D}{N_A}\rightarrow\frac{x_p}{x_n+x_p}=\frac{N_D}{N_A+N_D}$$

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

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

$$V_D=\frac{q}{2\varepsilon_r\varepsilon_0}\frac{N_AN_D}{N_A+N_D}X_D^2$$

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

p⁺- n结 $N_A>>N_D$

$$X_D=\sqrt{\frac{2\varepsilon_r\varepsilon_0V_D}{qN_D}}$$

$$X_D\approx x_n$$

n⁺- p结 $N_D>>N_A$

$$X_D=\sqrt{\frac{2\varepsilon_r\varepsilon_0V_D}{qN_A}}\rightarrow X_D\approx x_p$$

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8.2 p-n结电流电压特性5

8.2.1 p-n结中的电场和电势分布

一线性缓变结

杂质浓度梯度

电荷分布 $\rho(x)=q(N_D-N_A)=q\alpha x$

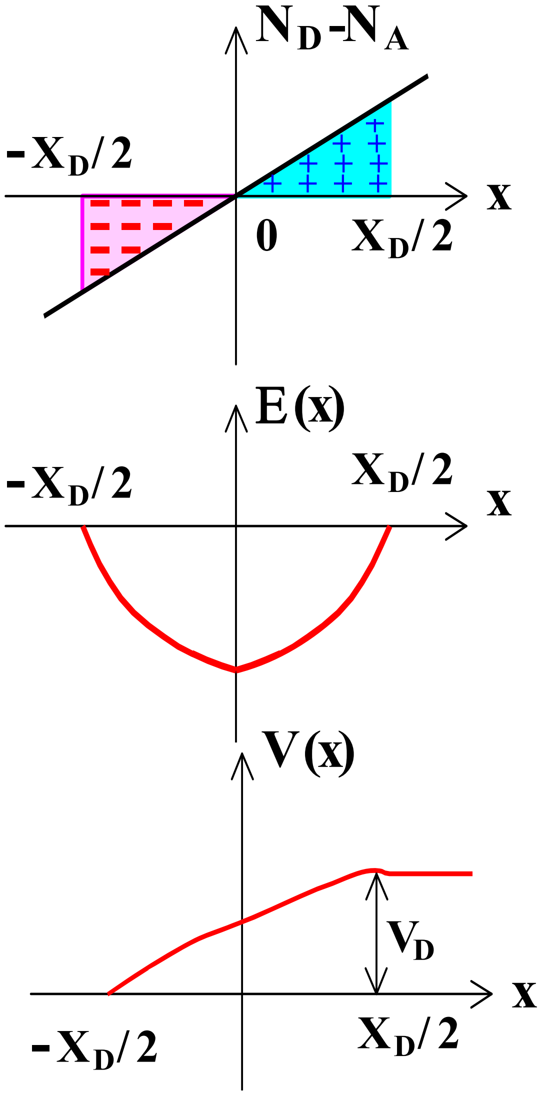
泊松方程 $\dfrac{d^2V}{dx^2}=-\dfrac{q\alpha x}{\varepsilon_r\varepsilon_0}$　$x=\pm\dfrac{X_D}{2}$，$\mathrm{E}(x)=0$

电场分布 $\mathrm{E}(x)=-\int\dfrac{d^2V}{dx^2}dx=\dfrac{q\alpha}{2\varepsilon_r\varepsilon_0}\left[x^2-\left(\dfrac{X_D}{2}\right)^2\right]$

电势分布 $V(x)=-\int \mathrm{E}(x)dx=\dfrac{q\alpha}{2\varepsilon_r\varepsilon_0}\left[\left(\dfrac{X_D}{2}\right)^2x-\dfrac{1}{3}x^3\right]$

$$V_D=V\left(\frac{X_D}{2}\right)-V\left(-\frac{X_D}{2}\right)=\frac{q\alpha}{12\varepsilon_r\varepsilon_0}X_D^3$$

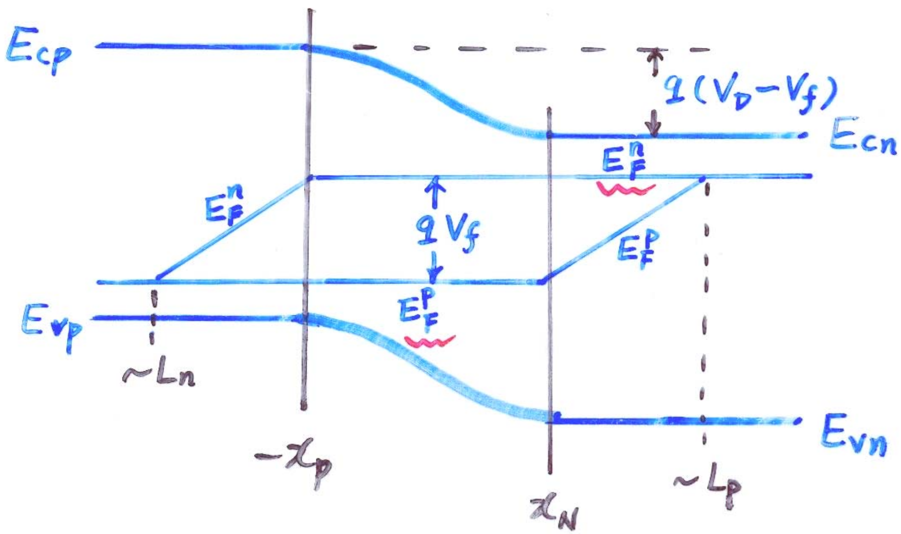
$$X_D=\left(\frac{12\varepsilon_r\varepsilon_0V_D}{q\alpha}\right)^{\frac{1}{3}}$$



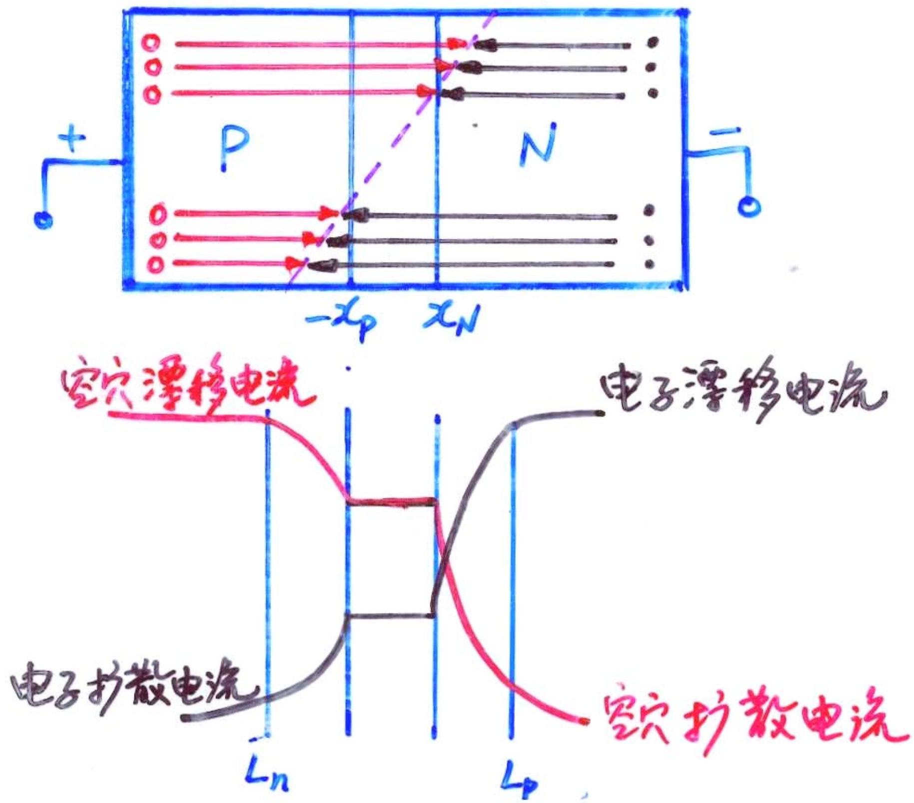
8.2 p-n结电流电压特性6

8.2.2 非平衡p-n结的能带图

正向偏压V_f下的能带图



四种电流的动态平衡



中性区	扩散区	耗尽区	扩散区	中性区

P型　N型

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8.2 p-n结电流电压特性7

8.2.2 p-n结电流-电压特性

—非平衡p-n结的能带图

—电压完全降在势垒区