半导体物理

主讲人：蒋玉龙

微电子学楼312室，65643768

Email: yljiang@fudan.edu.cn

http://10.14.3.121

第九章 金半接触

9.1 金半接触的能带图

9.2 金半接触的整流输运理论

9.3 少子注入和欧姆接触

9.1 金半接触的能带图1

9.1.1 功函数和电子亲合能

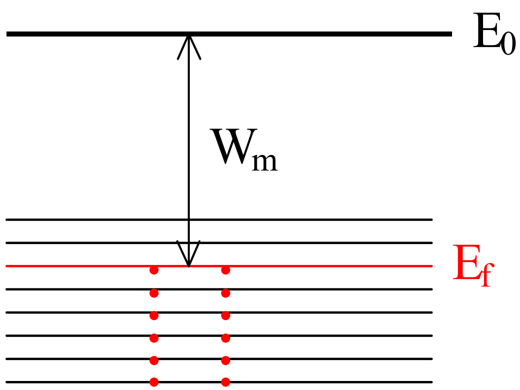
功函数： $W = E_0 - E_f$

—真空能级与费米能级之差

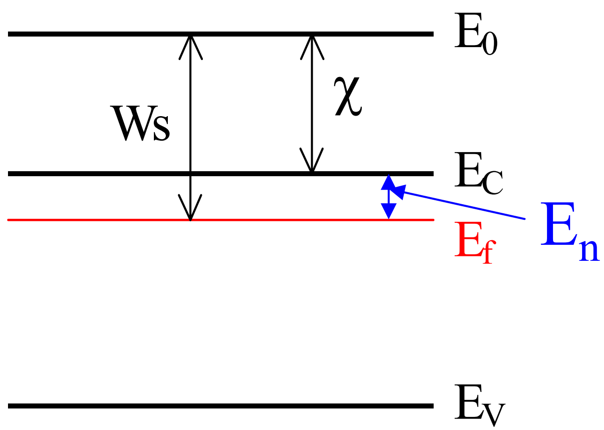
真空能级E_0：

真空中静止电子的能量

电子亲和能χ：真空能级与导带底之差



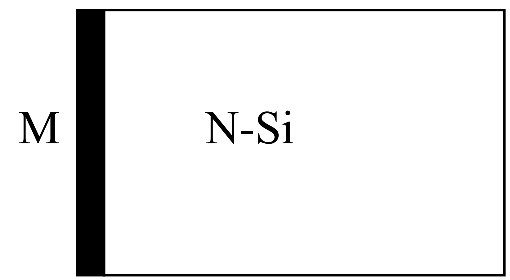
$$W_m = E_0 - E_F$$



$$W_s = E_0 - E_F$$

$$\chi = E_0 - E_C$$

$$E_n = E_c - E_f$$



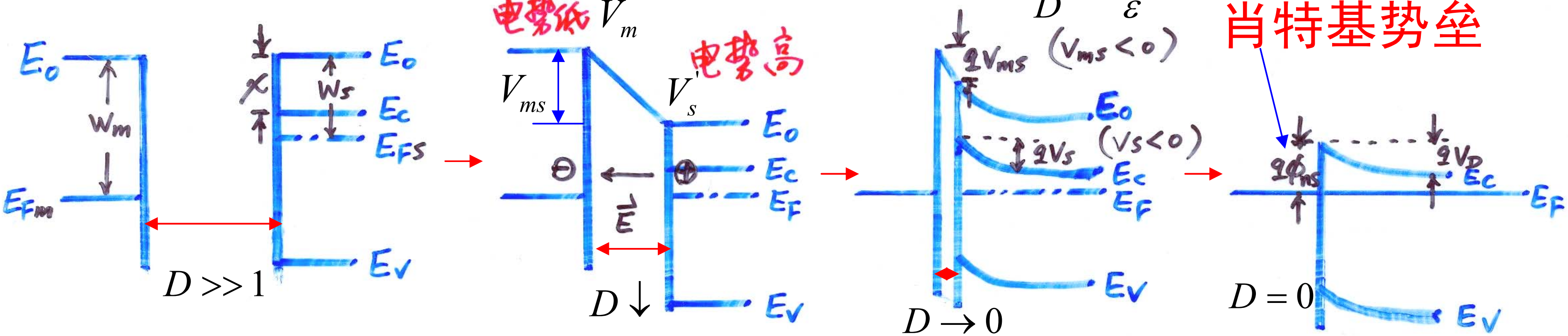
9.1 金半接触的能带图2

9.1.2 接触电势差

$0 > V_{ms} = V_m - V_s'$

$E = \frac{|V_{ms}|}{D} = \frac{\sigma}{\varepsilon} \uparrow$

肖特基势垒



（$W_m > W_s$）

$qV_{ms} = W_s - W_m$ 　　 $qV_{ms} + qV_s = W_s - W_m$ 　　 $q\phi_{ns} = W_m - \chi$

接触电势差 $V_{ms} = V_m - V_s'$

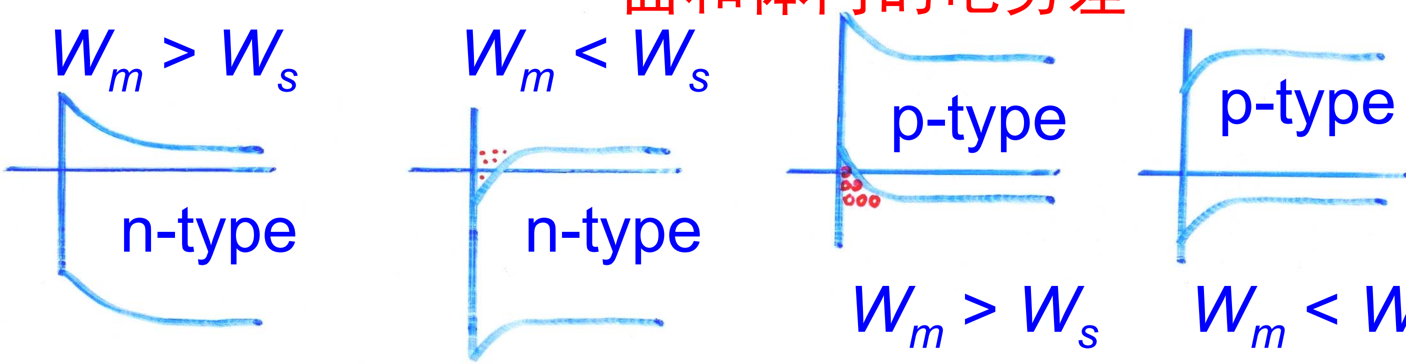
表面势：半导体表面和体内的电势差

$qV_D = W_m - W_s$

阻挡层：高阻，整流

反阻挡层：低阻，欧姆

$W_m > W_s$ 　　 $W_m < W_s$



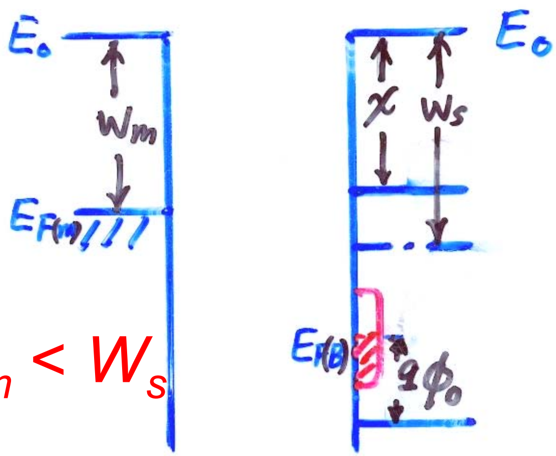
$W_m > W_s$ 　　 $W_m < W_s$

整流 　　 欧姆 　　 欧姆 　　 整流

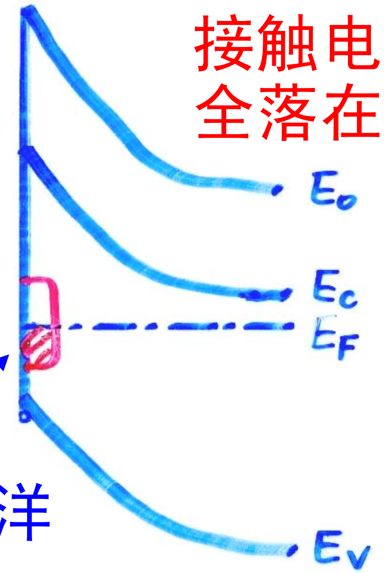
9.1 金半接触的能带图3

9.1.3 表面态对接触势垒的影响

$W_m < W_s$



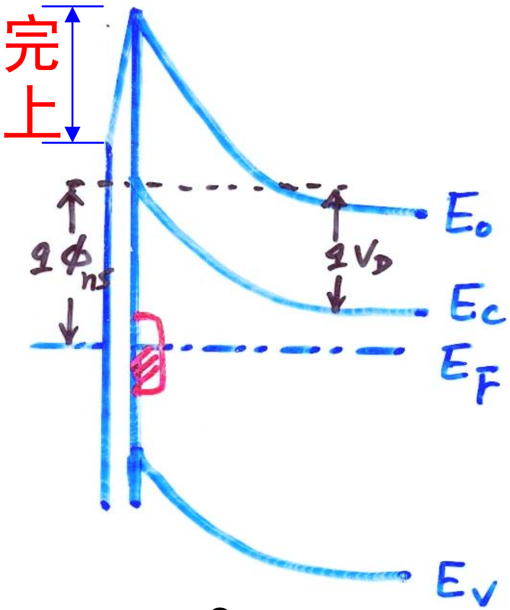
中性态



能态海洋

E_F 钉扎

接触电势差完全落在窄隙上



E_F 钉扎效应

$$\begin{cases} q\phi_{ns} \approx \dfrac{2}{3}E_g \\ qV_D \approx \dfrac{2}{3}E_g - (E_C - E_F) \end{cases}$$

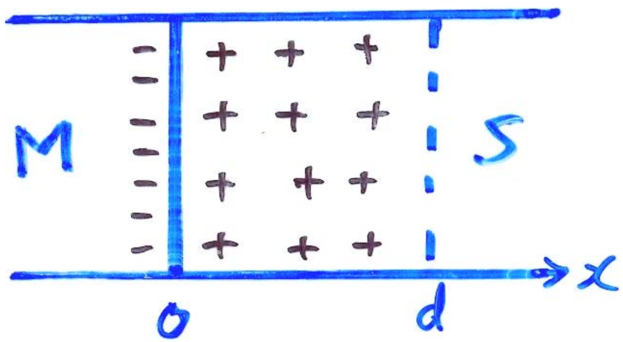
1° 势垒高度与金属功函数基本无关

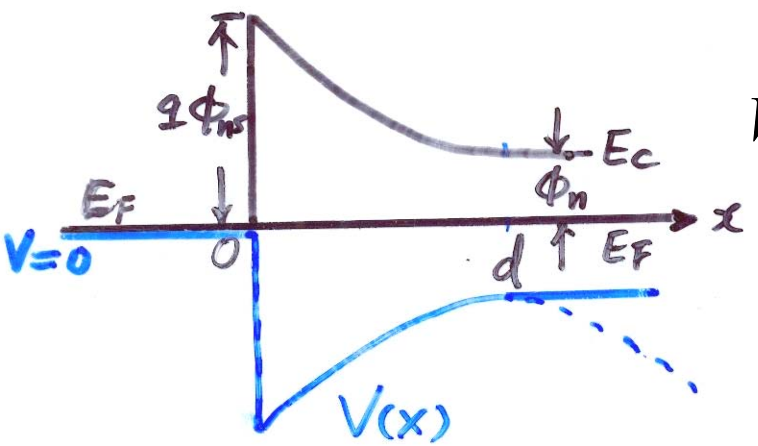
2° 即使$W_m < W_s$，阻挡层依然存在

9.1 金半接触的能带图4

9.1.4 势垒区的电势分布

一n型半导体





泊松方程

$$\frac{d^2V}{dx^2}=\begin{cases}-\dfrac{qN_D}{\varepsilon_0\varepsilon_r} & 0\le x\le d\\ 0 & x>d\end{cases}$$

$$E(x)=-\frac{dV}{dx}=\frac{qN_D}{\varepsilon_0\varepsilon_r}(x-d) \qquad \boxed{E(d)=0}$$

$$V(x)=-\frac{qN_D}{2\varepsilon_0\varepsilon_r}\left(x^2-2xd\right)-\phi_{ns} \qquad \boxed{V(0)=-\phi_{ns}}$$

$$\boxed{V(d)=-\phi_n \qquad \phi_{\mathrm{ns}}=\phi_n+V_D}$$

$$d=\left[\frac{2\varepsilon_0\varepsilon_r}{qN_D}(\phi_{ns}-\phi_n)\right]^{1/2}=\left(\frac{2\varepsilon_0\varepsilon_r}{qN_D}V_D\right)^{1/2}$$

9.1 金半接触的能带图5

9.1.5 肖特基接触的势垒电容

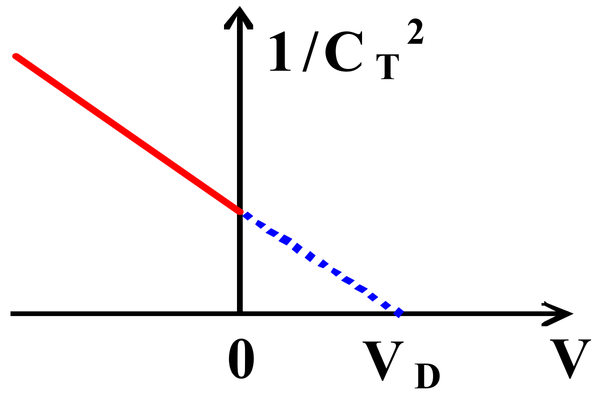
$$d=\left[\frac{2\varepsilon_0\varepsilon_r}{qN_D}(\phi_{ns}-\phi_n)\right]^{1/2}=\left(\frac{2\varepsilon_0\varepsilon_r}{qN_D}V_D\right)^{1/2}$$

施加反向偏压V时

$$d=\left[\frac{2\varepsilon_0\varepsilon_r}{qN_D}(V_D-V)\right]^{\frac{1}{2}}$$

平行板电容

$$\boxed{C_T=A\frac{\varepsilon_0\varepsilon_r}{d}=A\left[\frac{\varepsilon_0\varepsilon_r qN_D}{2(V_D-V)}\right]^{1/2}}$$



与单边突变p-n结相同

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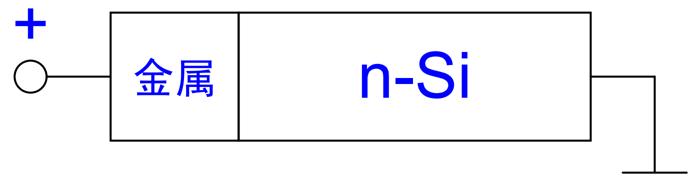
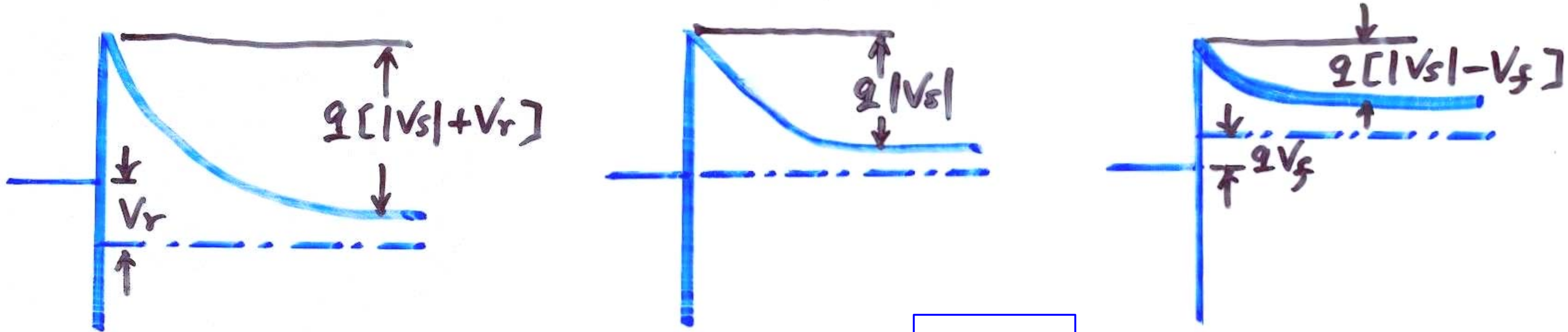
9.2 金半接触的整流输运理论1

9.2.1 扩散理论

—适用于势垒宽度>>电子平均自由程

$l_n << d$





同时考虑势垒区扩散和漂移电流

$$\boxed{\mu = \frac{q}{kT} D}$$

$$J = qn(x)\mu_n E(x) + qD_n \frac{dn(x)}{dx} = qD_n \left[-\frac{qn(x)}{kT}\frac{dV(x)}{dx} + \frac{dn(x)}{dx} \right]$$

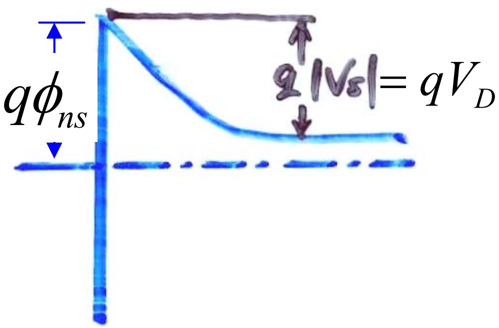
$$\boxed{E(x) = -\frac{dV}{dx}}$$

$$J \exp\left[-\frac{qV(x)}{kT}\right] = qD_n \frac{d}{dx}\left\{ n(x)\exp\left[-\frac{qV(x)}{kT}\right] \right\}$$

9.2 金半接触的整流输运理论2

9.2.1 扩散理论

积分 $\int_0^d dx$ $\longrightarrow$ $J\exp\left[-\frac{qV(x)}{kT}\right] = qD_n \frac{d}{dx}\left\{n(x)\exp\left[-\frac{qV(x)}{kT}\right]\right\}$



$$\int_0^d J\exp\left[-\frac{qV(x)}{kT}\right]dx \longleftarrow \boxed{V(x) = -\frac{qN_D}{2\varepsilon_0\varepsilon_r}\left(x^2 - 2xd\right) - \phi_{ns}}$$

$$= J\int_0^d \exp\left\{\frac{q}{kT}\left[\frac{qN_D}{2\varepsilon_0\varepsilon_r}\left(x^2 - 2xd\right) + \phi_{ns}\right]\right\}dx \longleftarrow \boxed{x^2 << 2xd}$$

$$\exp\left[-\frac{qV(x)}{kT}\right]$$

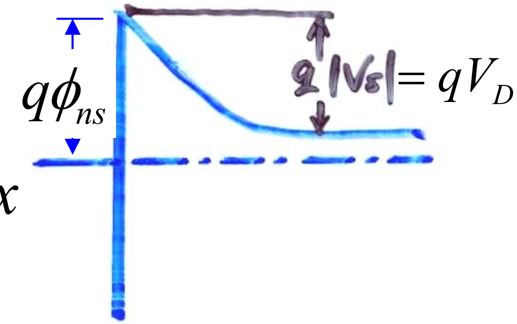
主要取决于x=0附近的电势值

$$\approx J\int_0^d \exp\left(\frac{q\phi_{ns}}{kT}\right)\exp\left(-\frac{q^2N_Dd}{\varepsilon_0\varepsilon_r kT}x\right)dx$$

$$= J\exp\left(\frac{q\phi_{ns}}{kT}\right)\frac{\varepsilon_0\varepsilon_r kT}{q^2N_Dd}\left[1 - \exp\left(-\frac{q^2N_Dd^2}{\varepsilon_0\varepsilon_r kT}\right)\right] \approx J\exp\left(\frac{q\phi_{ns}}{kT}\right)\frac{\varepsilon_0\varepsilon_r kT}{q^2N_Dd}$$

9.2 金半接触的整流输运理论3

9.2.1 扩散理论



积分

$$J\exp\left[-\frac{qV(x)}{kT}\right] = qD_n\frac{d}{dx}\left\{n(x)\exp\left[-\frac{qV(x)}{kT}\right]\right\} \leftarrow \int_0^d dx$$

平衡态近似

$$\boxed{\begin{aligned} n(0) &= n_0\exp(qV_{s0}/kT) \\ &= n_0\exp(-qV_D/kT)\end{aligned}}$$

$$\boxed{n(d) = n_0}$$

$$qD_n\left\{n(x)\exp\left[-\frac{qV(x)}{kT}\right]\right\}\Bigg|_0^d$$

$$\boxed{V(x) = -\frac{qN_D}{2\varepsilon_0\varepsilon_r}\left(x^2 - 2xd\right) - \phi_{ns}}$$

$$\boxed{V(0) = -\phi_{ns}}\quad \boxed{V(d) = \frac{qN_D}{2\varepsilon_r\varepsilon_0}d^2 - \phi_{ns}}$$

$$\boxed{V(d) = -\left[\phi_{ns} - \left(V_D - V\right)\right]}$$

$$= qD_n n_0\exp\left[\frac{q}{kT}\left(\phi_{ns} - V_D + V\right)\right] - qD_n n_0\exp\left(\frac{qV_{s0}}{kT}\right)\exp\left(\frac{q\phi_{ns}}{kT}\right)$$

$$\boxed{-V_D = V_{s0}}$$

$$= qD_n n_0\exp\left[q\left(V_{s0} + \phi_{ns}\right)/kT\right]\left[\exp\left(qV/kT\right) - 1\right]$$

9.2 金半接触的整流输运理论4

9.2.1 扩散理论

$$\int_0^d J\exp\left[-\frac{qV(x)}{kT}\right]dx=\int_0^d qD_n\frac{d}{dx}\left\{n(x)\exp\left[-\frac{qV(x)}{kT}\right]\right\}dx$$

$$\downarrow$$

$$J\exp\left(\frac{q\phi_{ns}}{kT}\right)\frac{\varepsilon_0\varepsilon_r kT}{q^2N_Dd}=qD_nn_0\exp\left[q\left(V_{s0}+\phi_{ns}\right)/kT\right]\left[\exp\left(qV/kT\right)-1\right]$$

$$\downarrow \quad \boxed{-V_D=V_{s0}}$$

$$J=\frac{q^3D_nn_0N_Dd}{\varepsilon_0\varepsilon_r kT}\exp\left(-qV_D/kT\right)\left[\exp\left(qV/kT\right)-1\right]$$

$$\downarrow \leftarrow \boxed{d=\left[\frac{2\varepsilon_0\varepsilon_r}{qN_D}\left(V_D-V\right)\right]^{\frac{1}{2}}}$$

$$=\underbrace{\frac{q^2D_nn_0}{kT}\left[\frac{2qN_D}{\varepsilon_0\varepsilon_r}\left(V_D-V\right)\right]^{1/2}\exp\left(-qV_D/kT\right)}_{J_{SD}}\left[\exp\left(qV/kT\right)-1\right]$$

$$\boxed{=J_{SD}\left[\exp\left(qV/kT\right)-1\right]}$$

—适用于势垒宽度>>电子平均自由程