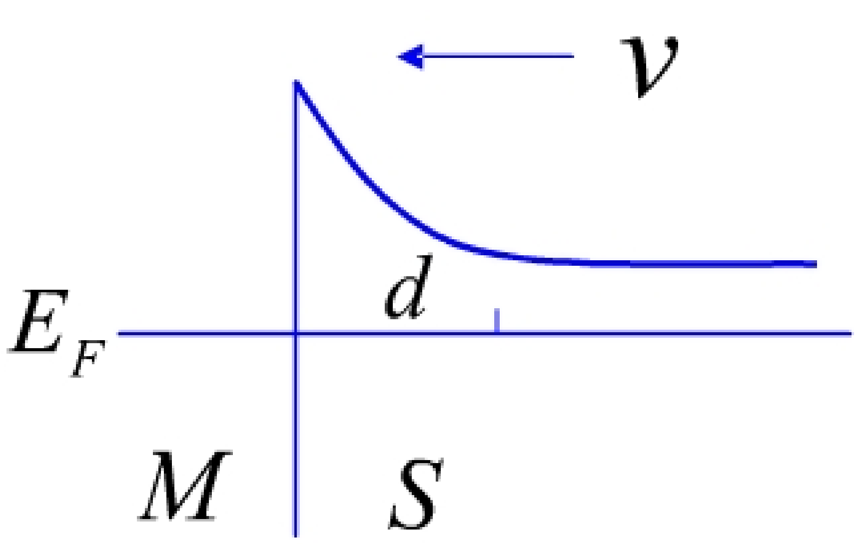
9.2 金半接触的整流输运理论5

9.2.2 热电子发射理论



—适用于势垒宽度<<电子平均自由程 $l_n >> d$

$$E - E_C = \frac{m_n^*}{2}\left(v_x^2 + v_y^2 + v_z^2\right) = \frac{1}{2m_n^*}\left(P_x^2 + P_y^2 + P_z^2\right)$$

单位动量空间$dP_x dP_y dP_z$中的状态数

$$2\frac{V}{(2\pi)^3}dk_x dk_y dk_z = \frac{2V}{\hbar^3(2\pi)^3}dP_x dP_y dP_z = \frac{2V}{h^3}dP_x dP_y dP_z$$

实空间单位体积中，动量空间单位体积$dP_x dP_y dP_z$中的电子数

$$dn' = \frac{2dP_x dP_y dP_z}{h^3}\exp\left(-\frac{E-E_F}{kT}\right) = \frac{2dP_x dP_y dP_z}{h^3}\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]\exp\left(-\frac{E_C-E_F}{kT}\right)$$

$$= \frac{2m_n^{*3}}{h^3}\exp\left(-\frac{E_C-E_F}{kT}\right)\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]dv_x dv_y dv_z$$

$$\boxed{n_0 = 2\frac{\left(2\pi m_n^* kT\right)^{\frac{3}{2}}}{h^3}\exp\left(-\frac{E_c-E_F}{kT}\right)}$$

$$= n_0\left(\frac{m_n^*}{2\pi kT}\right)^{3/2}\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]dv_x dv_y dv_z$$

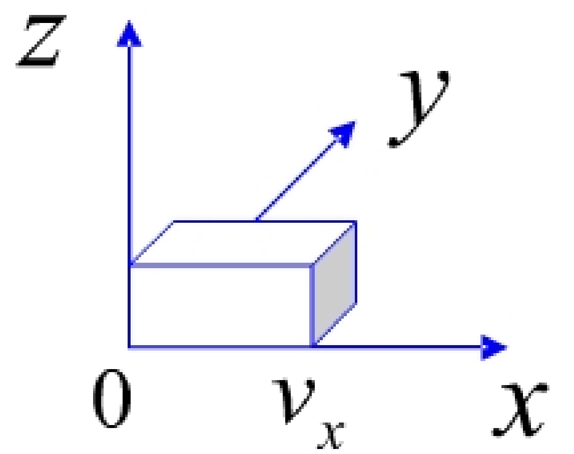
速度空间单位体积中的电子数

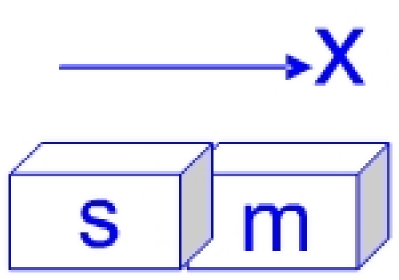
9.2 金半接触的整流输运理论6

9.2.2 热电子发射理论

实空间单位体积，速度空间电子的分布

$$dn' = n_0\left(\frac{m_n^*}{2\pi kT}\right)^{3/2}\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]dv_x dv_y dv_z$$





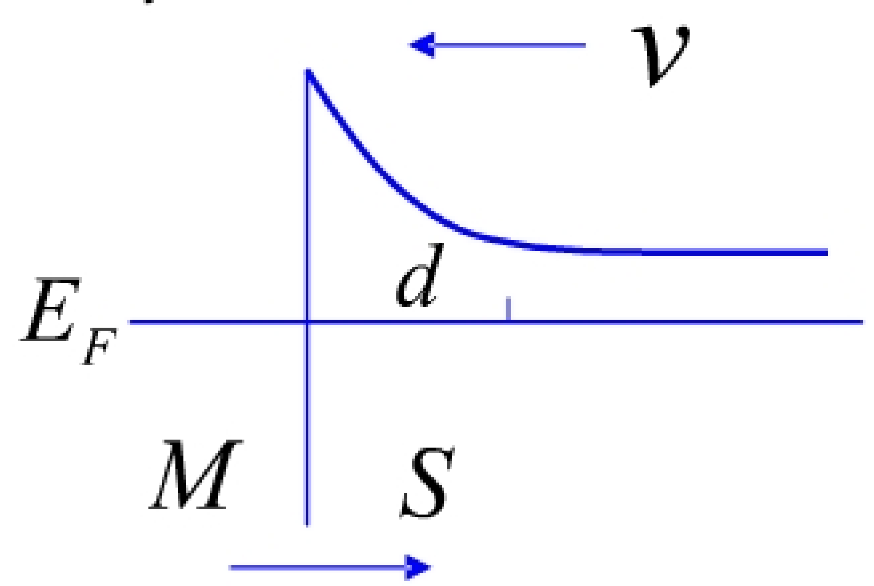
$l_n >> d$

实空间单位面积，单位时间，速度v_x(>0)的电子都可以到达金半界面，其数目为

$$dN = n_0\left(\frac{m_n^*}{2\pi kT}\right)^{3/2}\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]v_x dv_x dv_y dv_z$$

可以越过势垒电子的能量要求

$$\boxed{\frac{1}{2}m_n^* v_{x0}^2 = q(V_D - V)}$$



v_x 积分限: $v_{x0} \to +\infty$

v_y 积分限: $-\infty \to +\infty$

v_z 积分限: $-\infty \to +\infty$

→ 电流密度

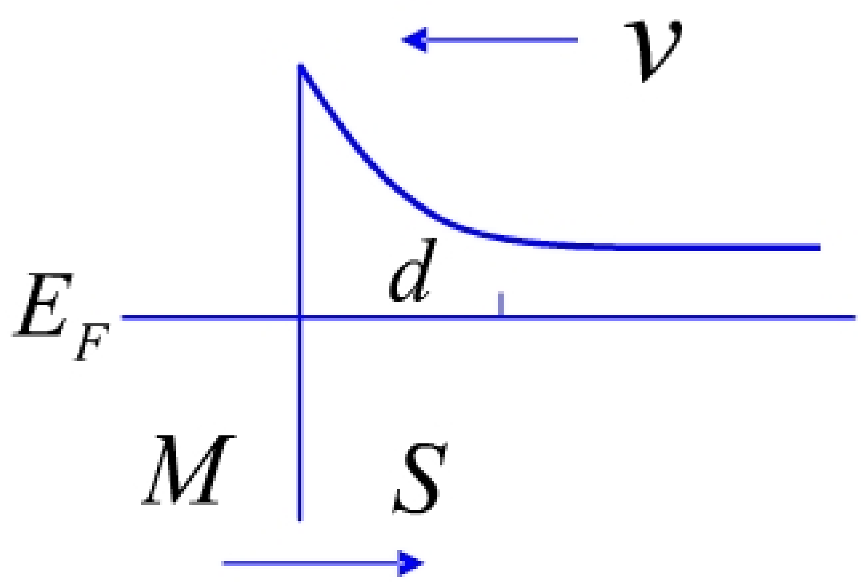
$$J_{s\to m} = \iiint n_0\left(\frac{m_n^*}{2\pi kT}\right)^{3/2}\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]\cdot q v_x dv_x dv_y dv_z$$

9.2 金半接触的整流输运理论7

9.2.2 热电子发射理论

$$J_{s\to m}=\iiint n_0\left(\frac{m_n^*}{2\pi kT}\right)^{3/2}\exp\left[-\frac{m_n^*\left(v_x^2+v_y^2+v_z^2\right)}{2kT}\right]\cdot qv_x dv_x dv_y dv_z$$

v_x：$v_{x0}\to+\infty$； v_y：$-\infty\to+\infty$； v_z： $-\infty\to+\infty$



$$=qn_0\left(\frac{kT}{2\pi m_n^*}\right)^{1/2}\exp\left(-m_n^* v_{x0}^2/2kT\right)$$

$$\frac{1}{2}m_n^* v_{x0}^2=q(V_D-V)$$

$$=\frac{4\pi q m_n^* k^2}{h^3}T^2\exp\left(-q\phi_{ns}/kT\right)\exp\left(qV/kT\right)$$

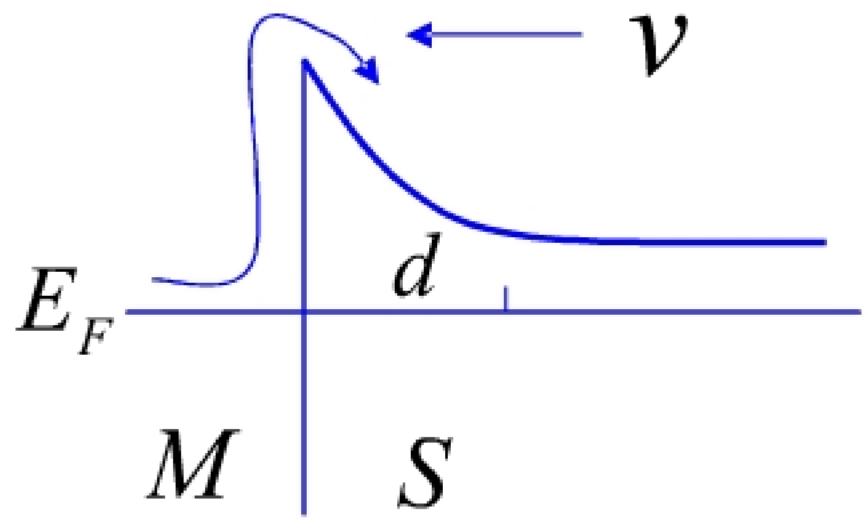
$$=A^* T^2\exp\left(-q\phi_{ns}/kT\right)\exp\left(qV/kT\right)$$

—半导体到金属的电子流依赖于电压

A^* = 120 (m_n^*/m_0) [$\mathrm{Acm^{-2}K^{-2}}$]

9.2 金半接触的整流输运理论8

9.2.2 热电子发射理论



—金属到半导体的电子流基本不依赖于电压

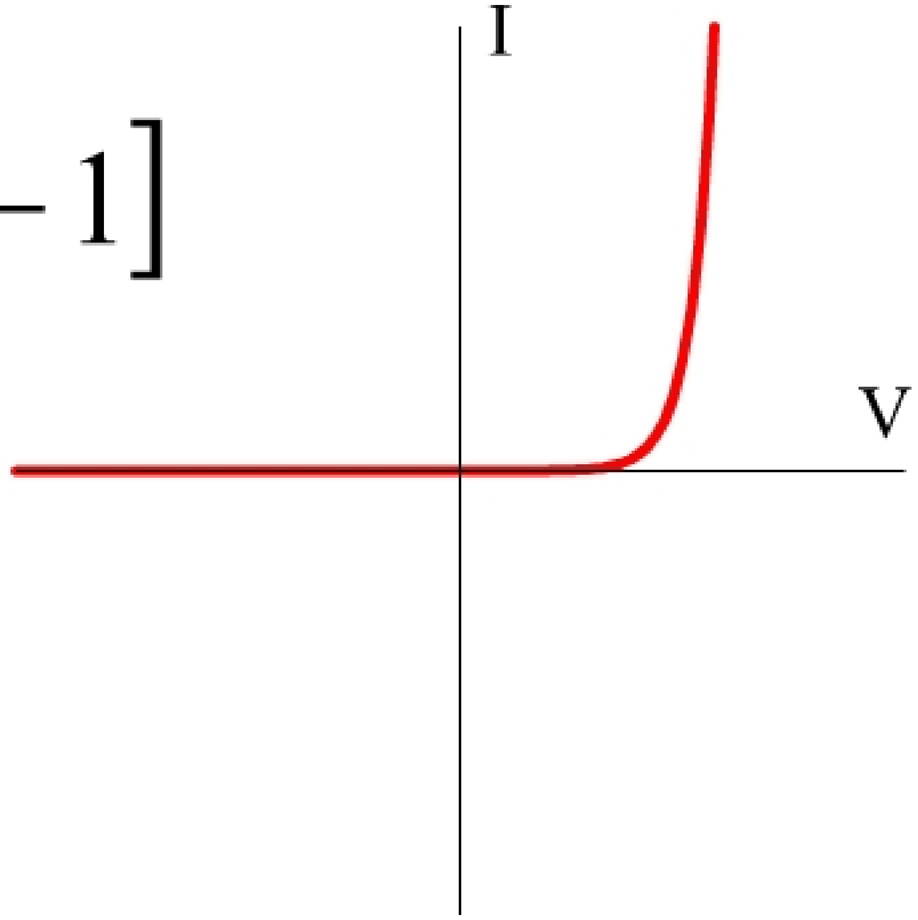
$J_{m\to s}$： 常数

$V=0,\ J=0 \longrightarrow J_{m\to s}\big|_{V=0} = -J_{s\to m}\big|_{V=0} = -A^*T^2\exp\left(-q\phi_{ns}/kT\right)$

$$J(V) = J_{s\to m}(V) + J_{m\to s}(0)$$

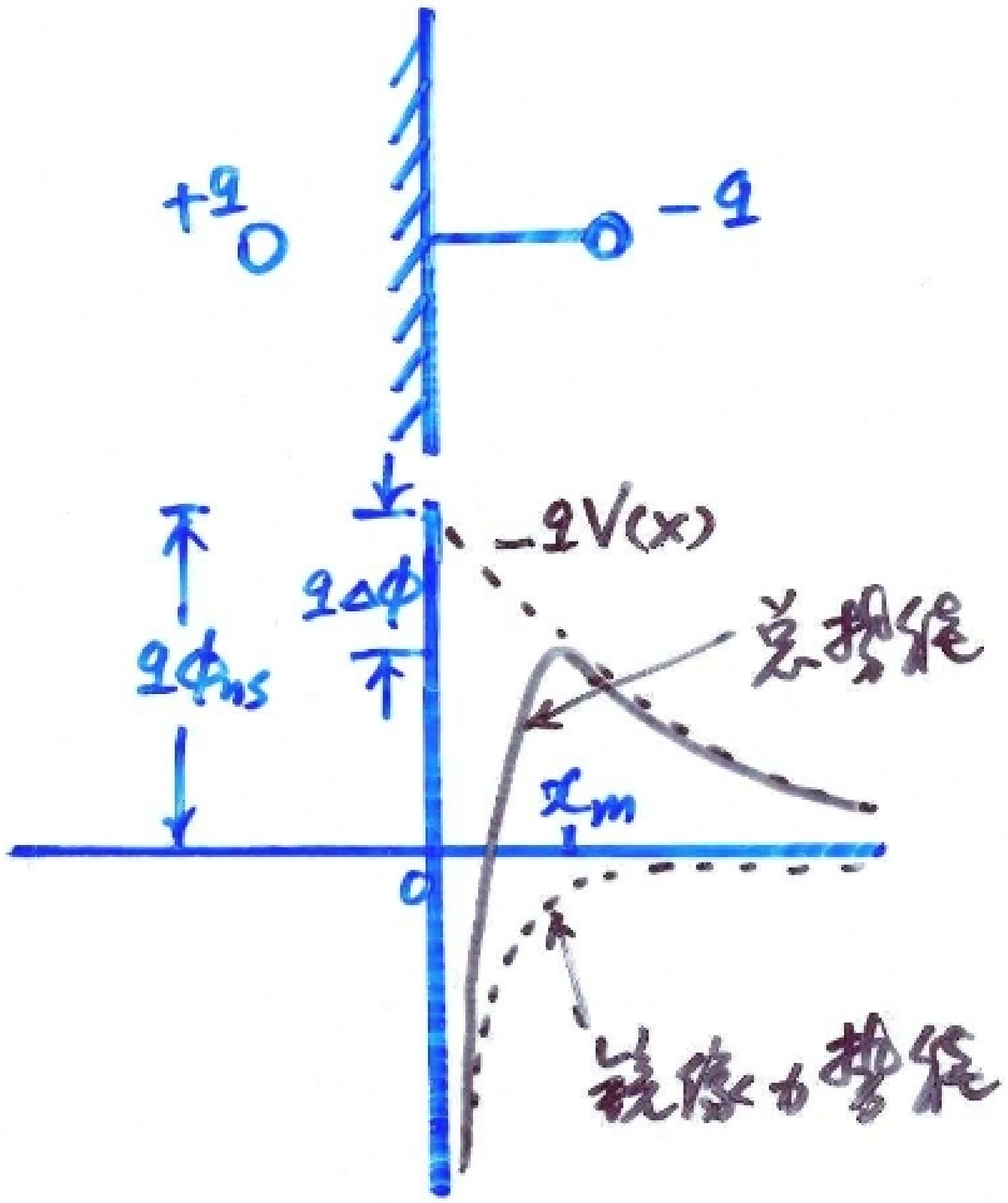
$$= A^*T^2\exp\left(-q\phi_{ns}/kT\right)\left[\exp\left(qV/kT\right)-1\right]$$

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



9.2 金半接触的整流输运理论9

9.2.3 镜像力影响



$$f_{im} = -\frac{q^2}{4\pi\varepsilon_0\varepsilon_r(2x)^2}$$

$$U_{im}(x) = \int_x^{\infty} f_{im}dx = -\frac{q^2}{16\pi\varepsilon_0\varepsilon_r x}$$

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

电子总电势能

$$U(x) = -\frac{q^2}{16\pi\varepsilon_0\varepsilon_r x} - qV(x)$$

$$\left.\frac{dU(x)}{dx}\right|_{x=x_m} = 0$$

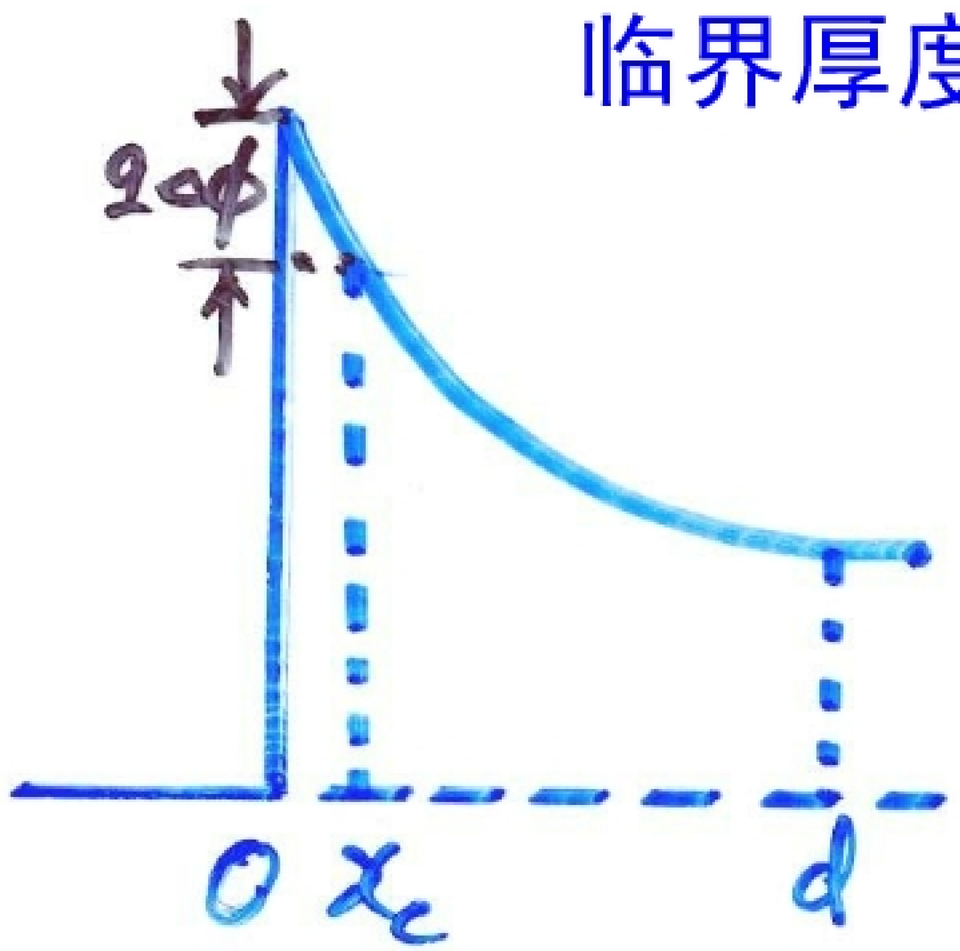
$x_m << d$

$$\longrightarrow x_m = \left(4\pi N_D d\right)^{-1/2}$$

$$q\Delta\phi = \frac{q^2 N_D}{\varepsilon_0\varepsilon_r}x_m d = \frac{1}{4}\left[\frac{2q^7 N_D}{\pi^2\varepsilon_0^3\varepsilon_r^3}(V_D - V)\right]^{1/4} \longleftarrow -qV(x_m) = q\phi_{ns} - \frac{q^2 N_D}{\varepsilon_0\varepsilon_r}x_m d$$

9.2 金半接触的整流输运理论10

9.2.4 隧道效应影响



临界厚度x_c

$$-qV(x_c) = -q\left[\frac{qN_D}{\varepsilon_0\varepsilon_r}\left(x_c d - \frac{x_c^2}{2}\right) - \phi_{ns}\right]$$

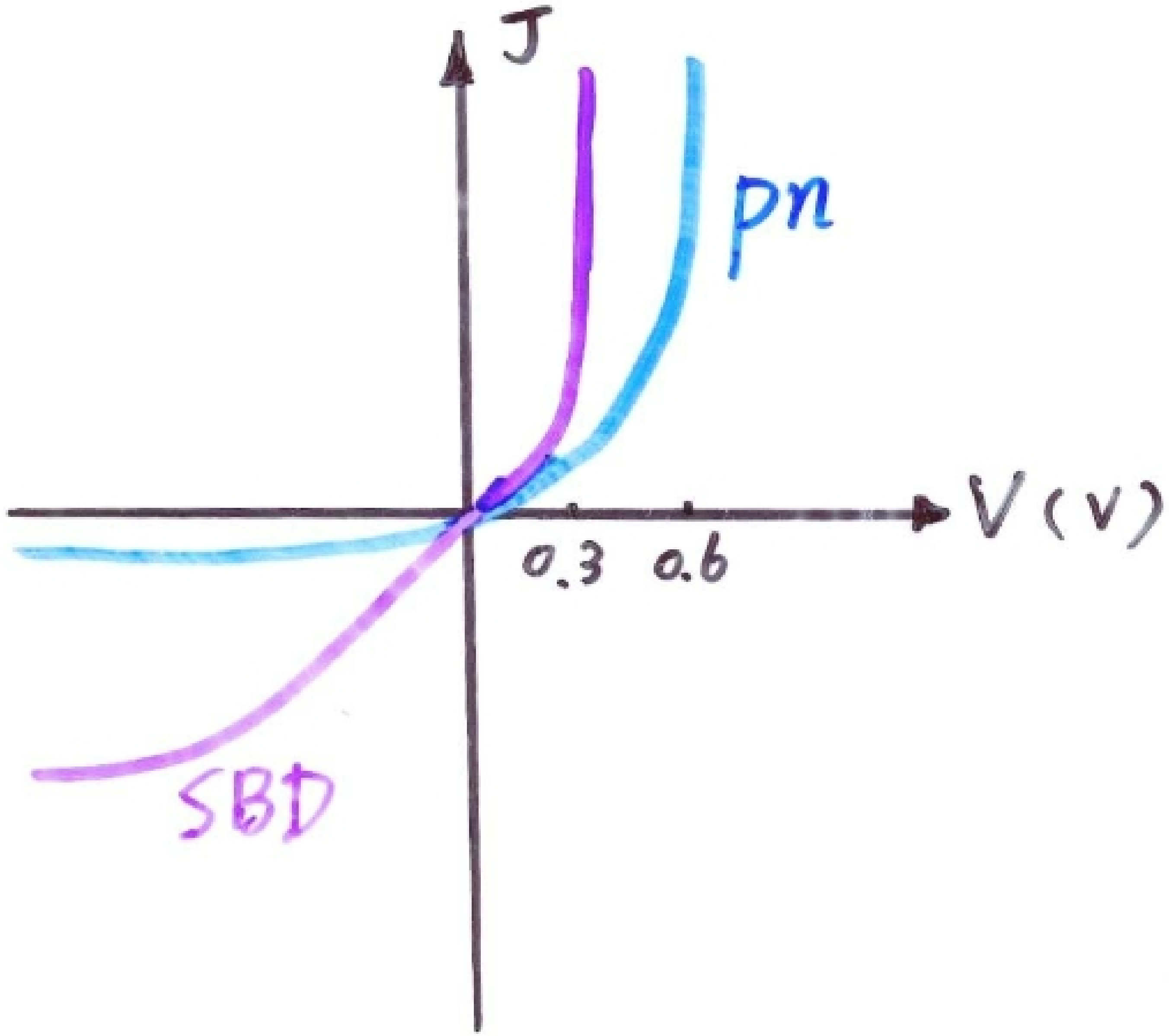
$x_c \ll d$

$$-qV(x_c) \approx q\phi_{ns} - \left[\frac{2q^3N_D}{\varepsilon_0\varepsilon_r}(V_D - V)\right]^{1/2} x_c$$

$$q\Delta\phi = \left[\frac{2q^3N_D}{\varepsilon_0\varepsilon_r}(V_D - V)\right]^{1/2} x_c$$

9.2 金半接触的整流输运理论11

9.2.5 pn结和肖特基势垒二极管



pn	SBD
少子器件， 电荷存贮效应	多子器件， 载流子无存贮
低频	高频
导通电压 ~ 0.6 V	导通电压 ~ 0.3 V

第九章 金半接触

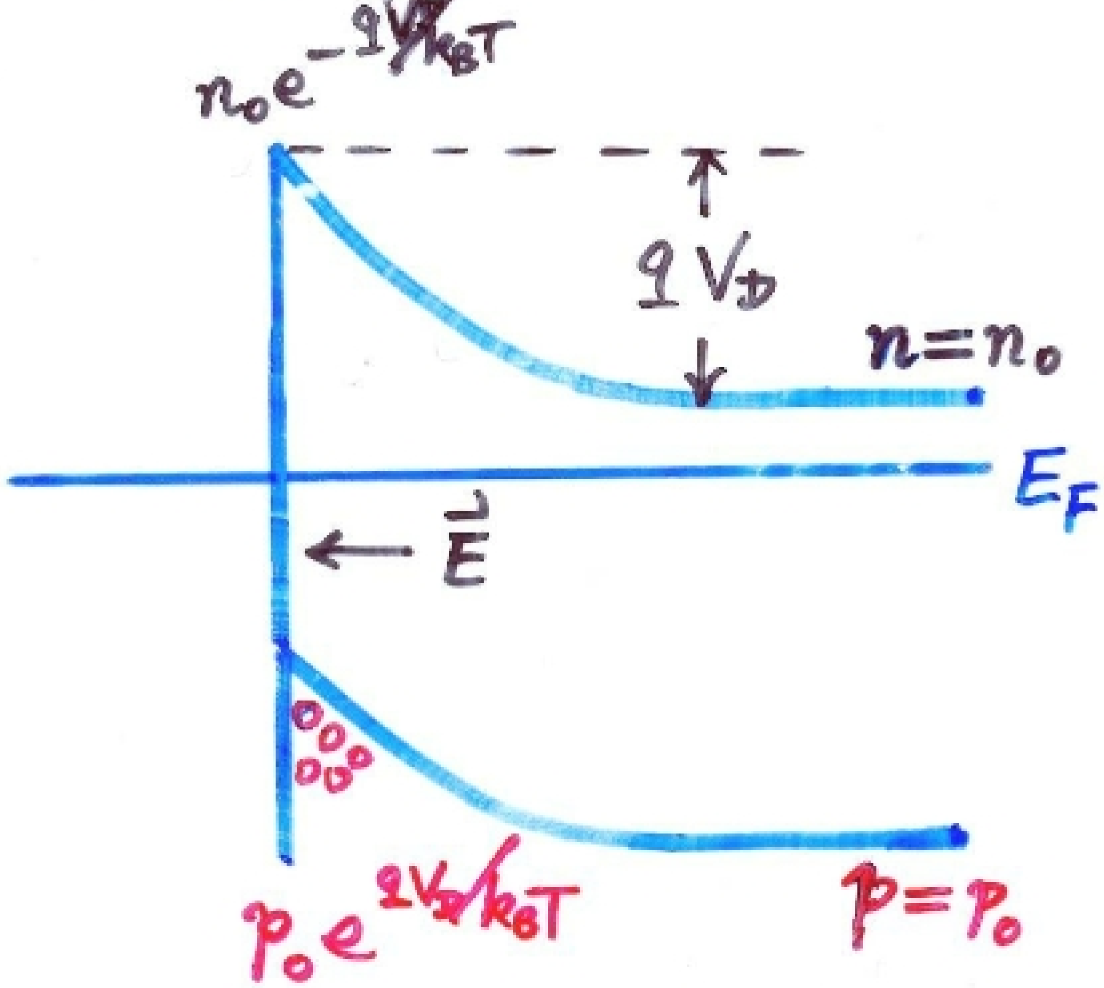
9.1 金半接触的能带图

9.2 金半接触的整流输运理论

9.3 少子注入和欧姆接触

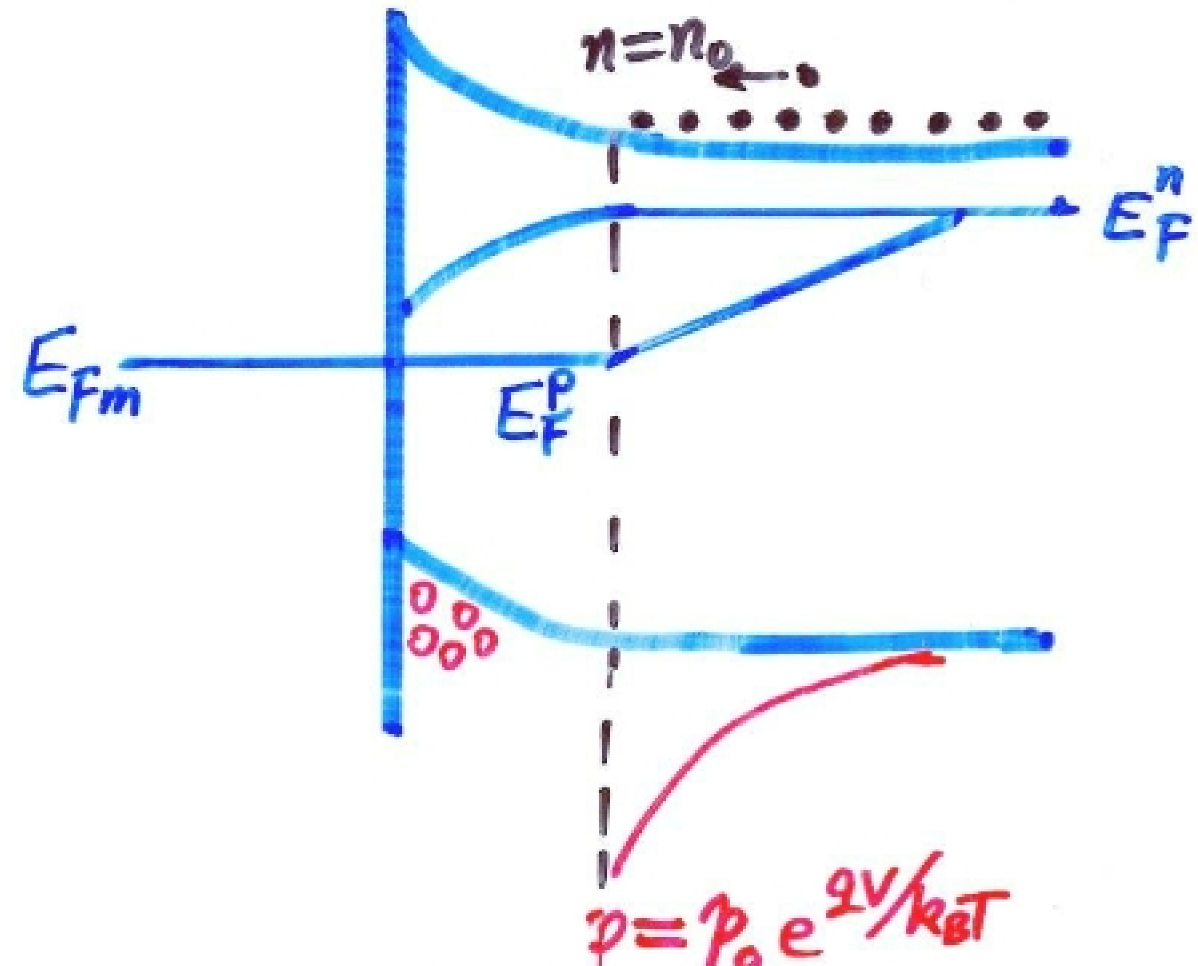
9.3 少子注入和欧姆接触1

9.3.1 少子注入



$V = 0$ (平衡态)

空穴扩散与电场抵消



$x = d$

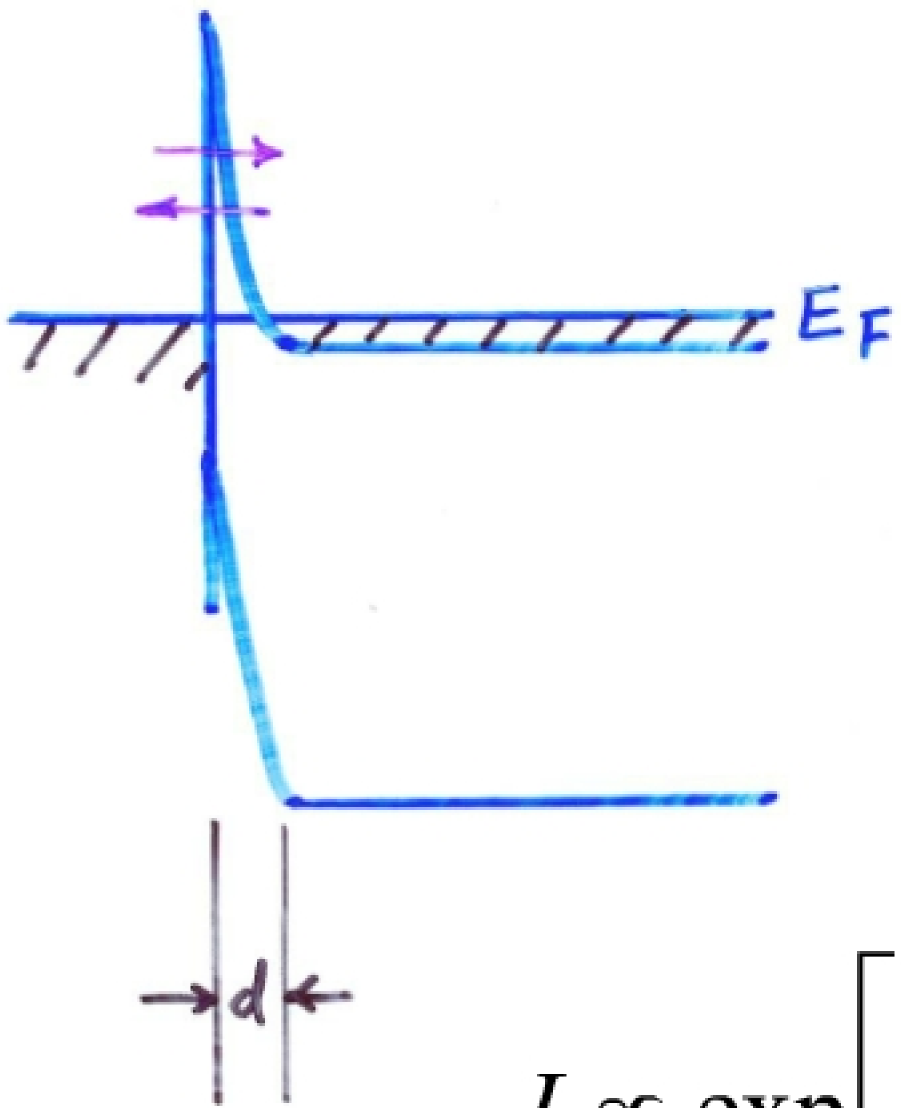
$V > 0$ (正偏) 空穴扩散主导

少子注入比

$$\gamma = \frac{J_p}{J} = \frac{J_p}{J_n + J_p}$$

9.3 少子注入和欧姆接触2

9.3.2 欧姆接触



金属－重掺杂半导体接触

$N_D = 10^{19}$ cm^{-3} $d \sim 10^2$ Å

电子隧穿通过势垒区

$$J_{s\to m} \propto \exp\left[-\frac{4\pi}{h}\left(\frac{m_n^*\varepsilon_0\varepsilon_r}{N_D}\right)^{1/2}(V_D - V)\right]$$

$$J_{m\to s} = C \equiv J_{m\to s}\big|_{V=0\,V} = J_{s\to m}\big|_{V=0\,V}$$

$$J \propto \exp\left[-\frac{4\pi}{h}\left(\frac{m_n^*\varepsilon_0\varepsilon_r}{N_D}\right)^{1/2}V_D\right]\left\{\exp\left[\frac{4\pi}{h}\left(\frac{m_n^*\varepsilon_0\varepsilon_r}{N_D}\right)^{1/2}V\right]-1\right\}$$

$N_D >> 1$

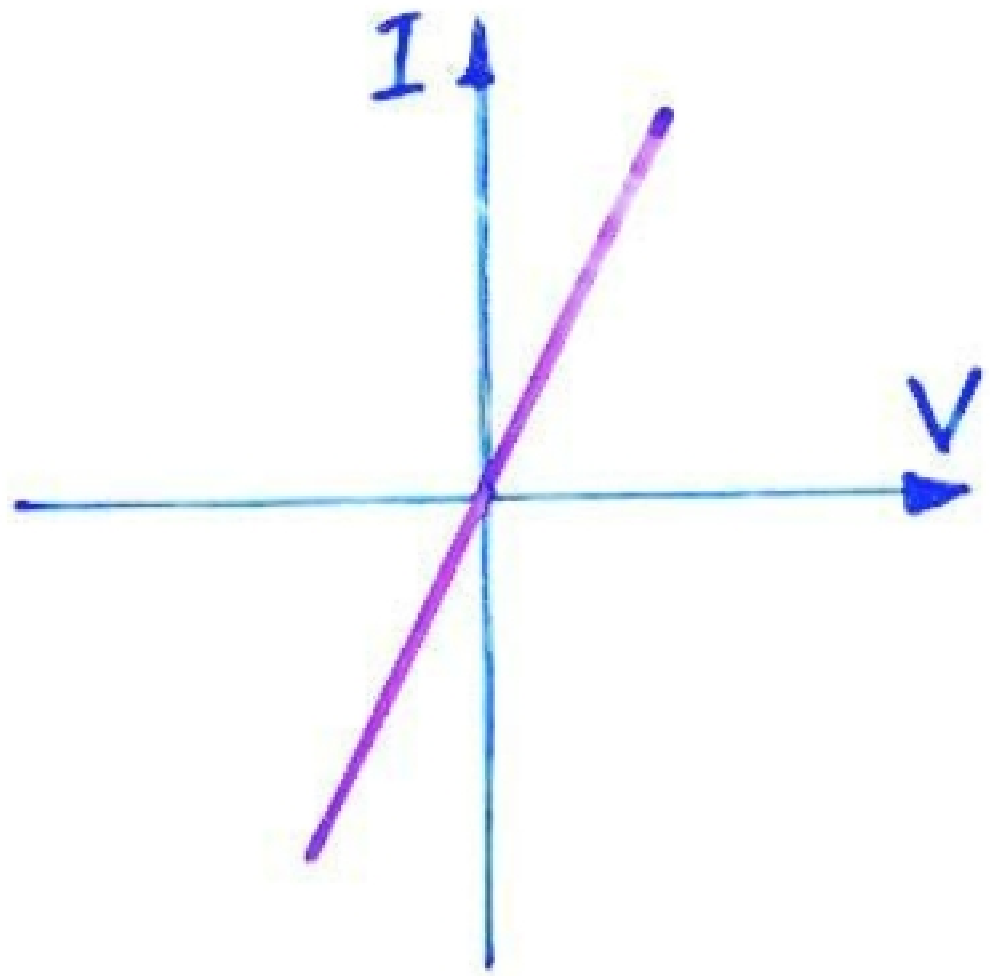
$$J \propto \frac{4\pi}{h}\left(\frac{m_n^*\varepsilon_0\varepsilon_r}{N_D}\right)^{1/2}\exp\left[-\frac{4\pi}{h}\left(\frac{m_n^*\varepsilon_0\varepsilon_r}{N_D}\right)^{1/2}V_D\right]\cdot V$$

$\boxed{\propto V}$

9.3 少子注入和欧姆接触3

9.3.2 欧姆接触

$$J \propto \frac{4\pi}{h}\left(\frac{m_n^* \varepsilon_0 \varepsilon_r}{N_D}\right)^{1/2} \exp\left[-\frac{4\pi}{h}\left(\frac{m_n^* \varepsilon_0 \varepsilon_r}{N_D}\right)^{1/2} V_D\right] \cdot V \boxed{\propto V}$$



1° 线性 *I-V*, 正反向对称

2° $R = \left(\frac{dI}{dV}\right)^{-1}$ 接触电阻很小