Condensed Matter Physic

Semiconductors

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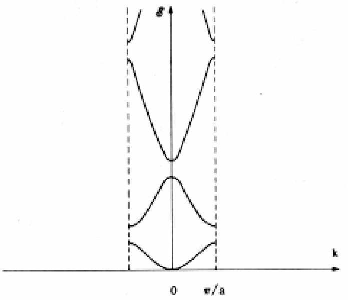
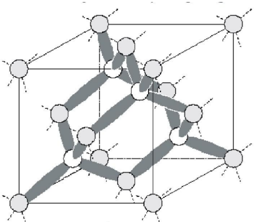
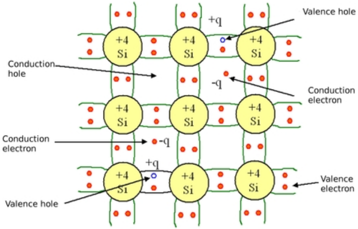
Semiconductor

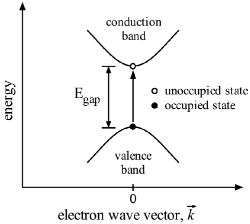




a)

Semiconductor





n-p excitation

density of states for type n

$$\rho_c(E) = \frac{1}{2\pi^2}\left(\frac{2m_n}{\hbar^2}\right)^{3/2}\sqrt{E - E_c}$$

density of states for type p

$$\rho_v(E) = \frac{1}{2\pi^2}\left(\frac{2m_p}{\hbar^2}\right)^{3/2}\sqrt{E_v - E}$$

mean value of n states

$$n(T) = \int_{E_c}^{\infty} \rho_c(E)\frac{1}{e^{\frac{E-\mu}{k_B T}} + 1}dE$$

$$p(T) = \int_{-\infty}^{E_v} \rho_v(E)\left[1 - \frac{1}{e^{\frac{E-\mu}{k_B T}} + 1}\right]dE$$

n-p excitation

$$p(T) = \int_{-\infty}^{E_v} \rho_v(E) \frac{1}{e^{\frac{\mu - E}{k_B T}} + 1} dE$$

$E - E_c >> k_B T$, classical approximation is good

$$n(T) = \int_{E_c}^{\infty} \rho_c(E) e^{-\frac{E-\mu}{k_B T}} dE = N_c(T) e^{-\frac{E_c - \mu}{k_B T}}$$

$$p(T) = \int_{-\infty}^{E_v} \rho_v(E) e^{-\frac{\mu - E}{k_B T}} dE = P_v(T) e^{-\frac{\mu - E_v}{k_B T}}$$

$$N_c(T) = \int_{E_c}^{\infty} \rho_c(E) e^{-\frac{E - E_c}{k_B T}} dE$$

n-p excitation

$$\int_0^\infty \sqrt{x} e^{-x} dx = \int_0^\infty 2y^2 e^{-y^2} dy = \frac{\sqrt{\pi}}{2}$$

$$N_c(T) = \int_{E_c}^\infty \rho_c(E) e^{-\frac{E-E_c}{k_B T}} dE = 2\left(\frac{m_e k_B T}{2\pi\hbar^2}\right)^{3/2}$$

$$P_v(T) = \int_{-\infty}^{E_c} \rho_v(E) e^{-\frac{E_v-E}{k_B T}} dE = 2\left(\frac{m_p k_B T}{2\pi\hbar^2}\right)^{3/2}$$

neutral superconductor

$$n(T) = p(T)$$

in the same time

$$n(T)p(T) = N_c(T)P_v(T)e^{-\frac{E_c - E_v}{k_B T}}$$

From this

$$n(T) = \sqrt{N_c(T)P_v(T)e^{-\frac{E_c - E_v}{2k_B T}}}$$

Chemical potential

$$N_c(T)e^{-\frac{E_c - \mu}{k_B T}} = P_v(T)e^{-\frac{\mu - E_v}{k_B T}}$$

$$\frac{P_v}{N_c} = \exp\left[\frac{2\mu - (E_c + E_v)}{k_B T}\right]$$

neutral superconductor

$$\mu = \frac{1}{2}(E_c + E_v) + \frac{1}{2}k_B T \ln\left(\frac{P_v(T)}{N_c(T)}\right)$$

If $m_p \approx m_n$

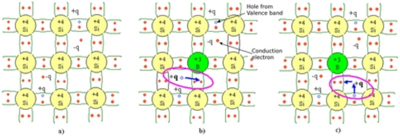
$$E_f = \frac{1}{2}(E_c + E_v)$$

So

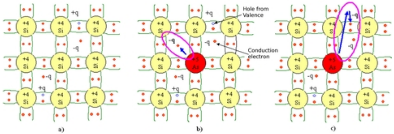
$$n(T) = 2\left(\frac{m_e k_B}{2\pi\hbar^2}\right)^{3/2} T^{3/2} e^{-\frac{E_f - E_v}{k_B T}}$$

Doped semiconductor

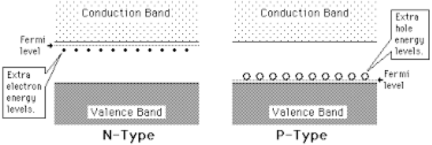
n type 5 valence (B)



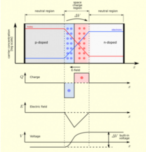
p type 3 valence (As)



Band structure

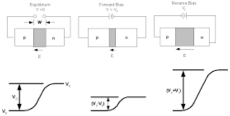


p-n transition

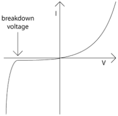


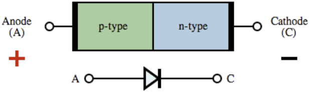
Perload

Equilibrium, Forward Bias, Reverse Bias Applied in a pn Junction



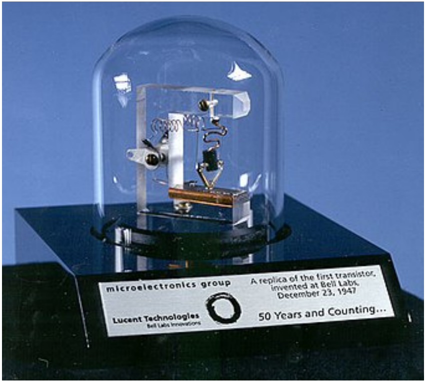
Voltage-current characteristic



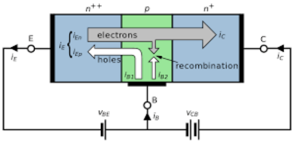


Transistor

Bardeen, Brattain,Shockley 1947, 1956



Transistor



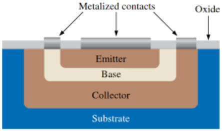
$$I_c = \alpha I_e \qquad \alpha \approx 0.95$$

Kirchhoff's law

$$I_e = I_c + I_b$$

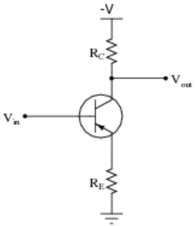
From this

$$I_c = \frac{\alpha}{1-\alpha} I_b = \beta I_b \qquad \beta \approx 100$$



(a) Basic epitaxial planar structure

Amplifier



$$
\begin{aligned}
U_{in} &= U_{be}(I_b) + R_e I_e \\
U_{out} &= U_t - R_c I_c
\end{aligned}
$$

$$
\begin{aligned}
U_{in} + \triangle U_{in} &= U_{be}(I_b + \triangle I_b) + R_e(I_e + \triangle I_e) \\
U_{out} + \triangle U_{out} &= U_t - R_c(I_c + \triangle I_c)
\end{aligned}
$$

Amplifier

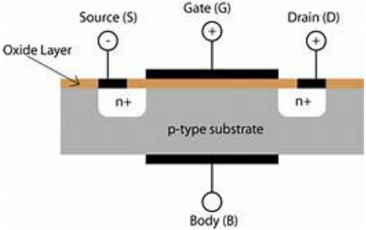
$$\begin{aligned} \triangle U_{in} &= U_{be}(I_b + \triangle I_b) - U_{be}(I_b) + R_e \triangle I_e \\ \triangle U_{out} &= -R_c \triangle I_c \end{aligned}$$

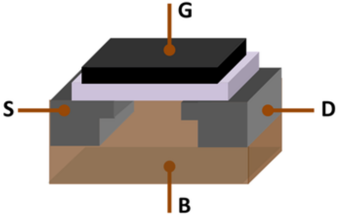
$$\begin{aligned} \triangle U_{in} &= R_B \triangle I_b + R_e \triangle I_e \\ \triangle U_{out} &= -R_c \triangle I_c \end{aligned}$$

$$\begin{aligned} \triangle U_{in} &= R_B \triangle I_b + R_e(1+\beta) \triangle I_b \\ \triangle U_{out} &= -R_c\beta \triangle I_b \end{aligned}$$

$$A = \frac{\triangle U_{out}}{\triangle U_{in}} = -\frac{\beta R_c}{R_B + R_e(1+\beta)} \approx -\frac{R_c}{R_e}$$

FET, MOSFET


Source (S)
Gate (G)
Drain (D)
Oxide Layer
n+
n+
p-type substrate
Body (B)


G
S
D
B