Kondenzált anyagok fizikája

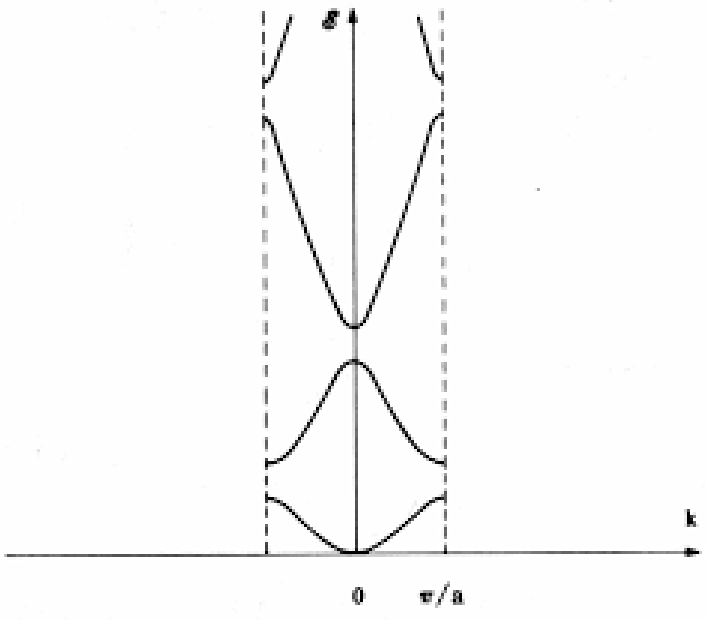
Félvezetők

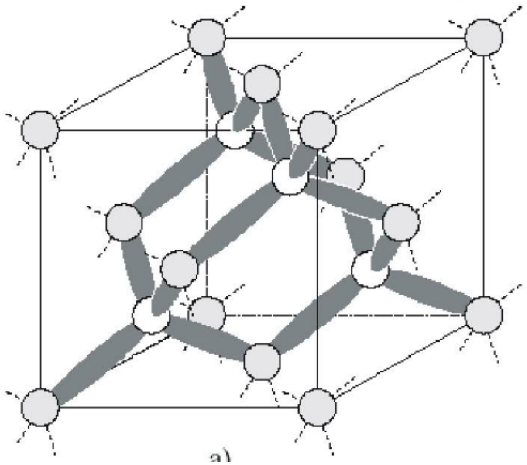
Groma István

ELTE

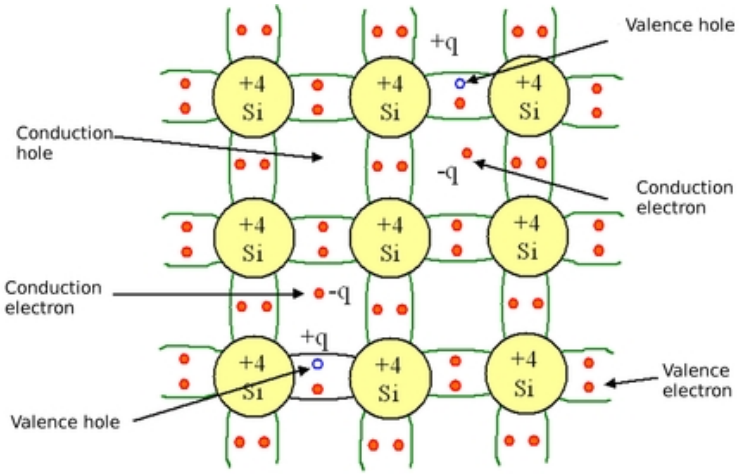
December 10, 2018

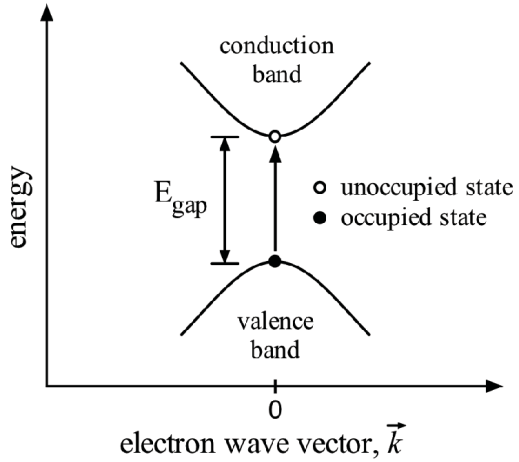
Félvezető





Félvezető


Valence hole
+q
+4
Si
Conduction
hole
-q
Conduction
electron
Conduction
electron
-q
+q
Valence
electron
Valence hole


conduction
band
energy
E_{gap}
unoccupied state
occupied state
valence
band
0
electron wave vector, $\vec{k}$

n-p gerjesztés

Állapotsűrűség n típus

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

Állapotsűrűség p típus

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

Betöltöttség

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

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

n-p gerjesztés

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

$E - E_c >> k_B T$, jó a klasszikus közelítés

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

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

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

n-p gerjesztés

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

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

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

Semleges félvezető

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

Ugyanakkor

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

Innen

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

Kémiai potenciál

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

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

Semleges félvezető

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

Ha $m_p \approx m_n$

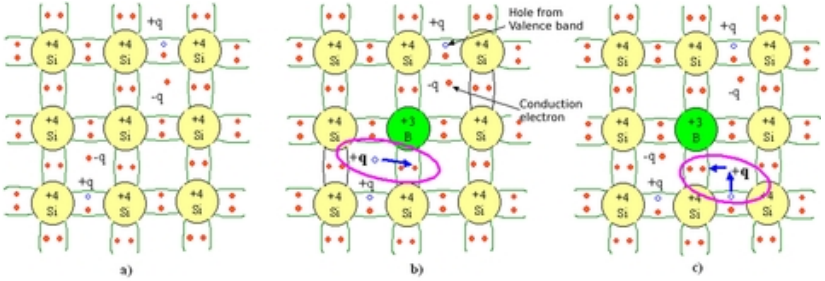
$$E_f = \frac{1}{2}(E_c + E_v)$$

Így

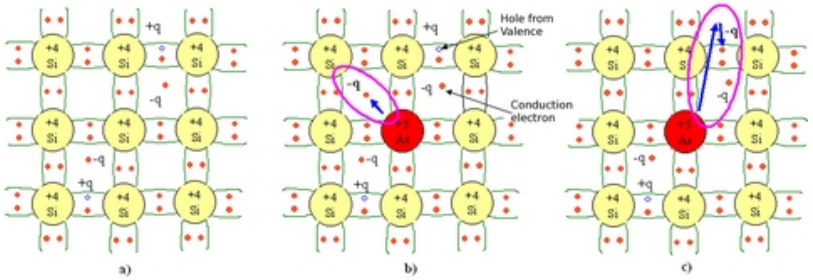
$$n(T) = 2\left(\frac{m_e k_B}{2\pi\hbar^2}\right)^{3/2} T^{3/2} e^{-\frac{E_f - E_v}{k_B T}}$$

Dópolt félvezető

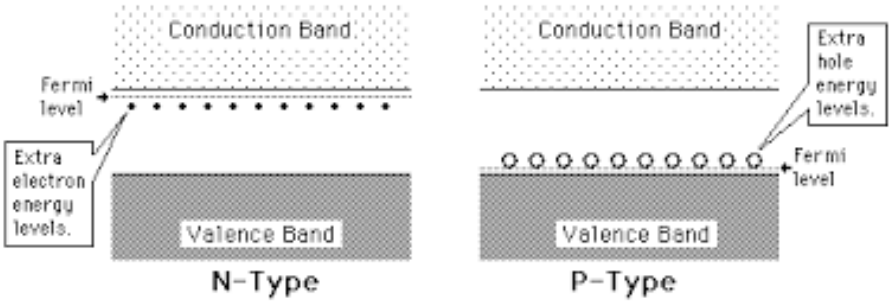
n típus 5 vegyérték (B)



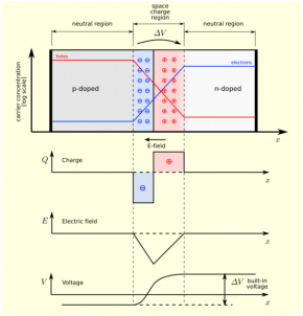
p típus 3 vegyérték (As)



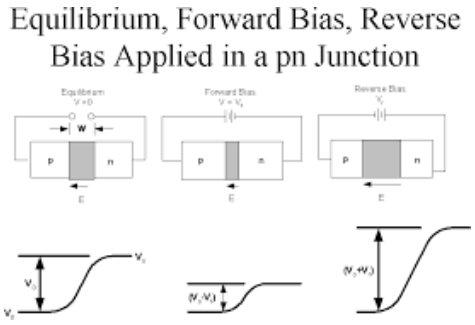
Sávszerkezet



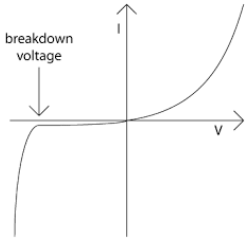
p-n átmenet

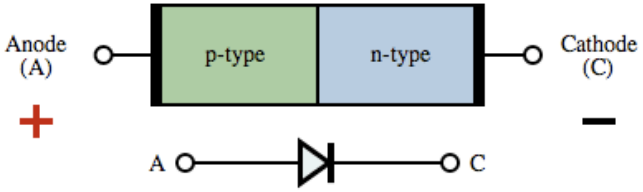


Előfeszítés



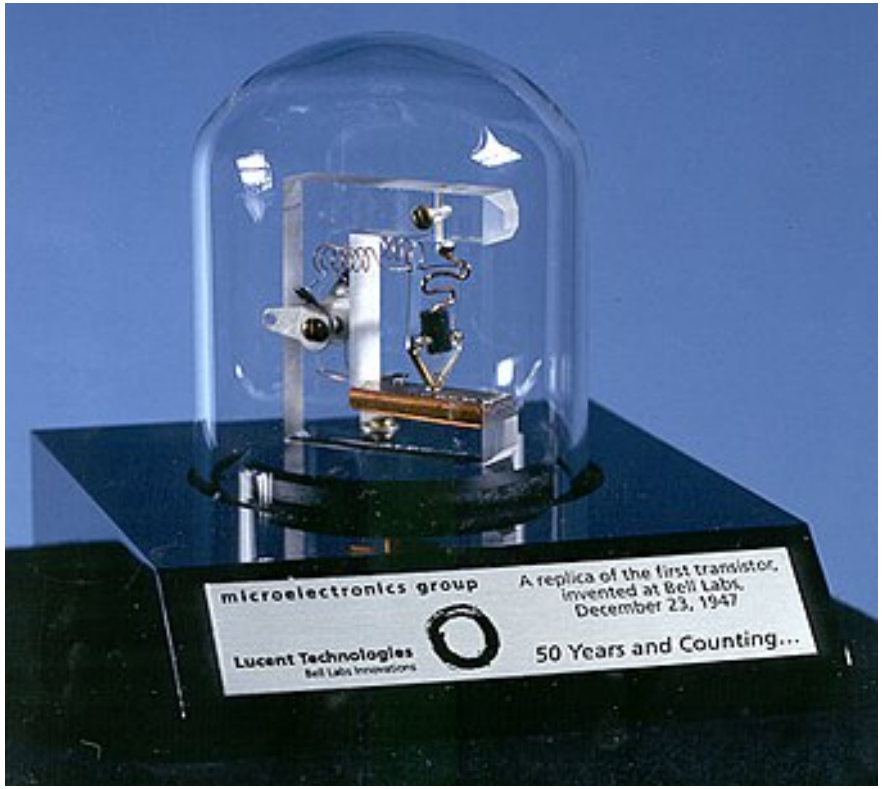
Feszültség-áram karakterisztika



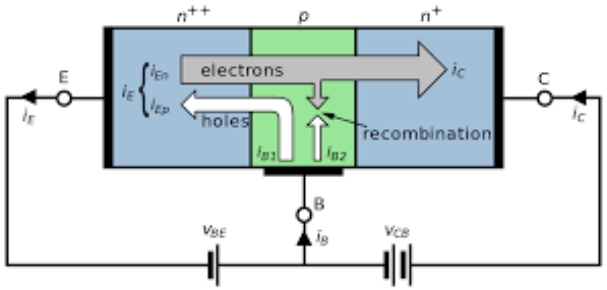


Transisztor

Bardeen, Brattain,Shockley 1947, 1956



Transisztor



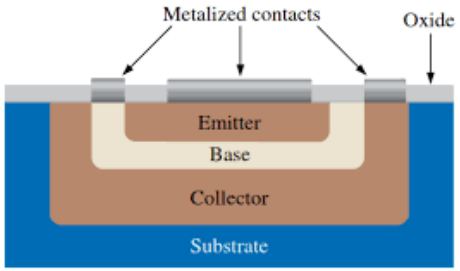
$$I_c = \alpha I_e \qquad \alpha \approx 0.95$$

Kirchoff törvény

$$I_e = I_c + I_b$$

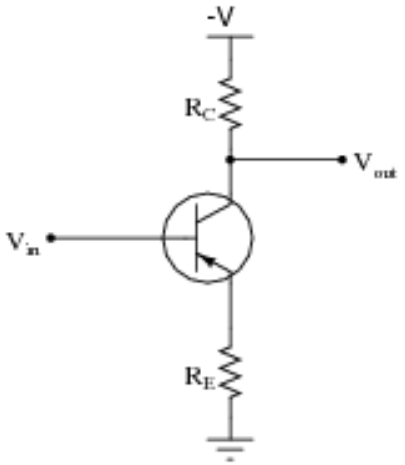
Innen

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



(a) Basic epitaxial planar structure

Erősítő



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

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

Erősítő

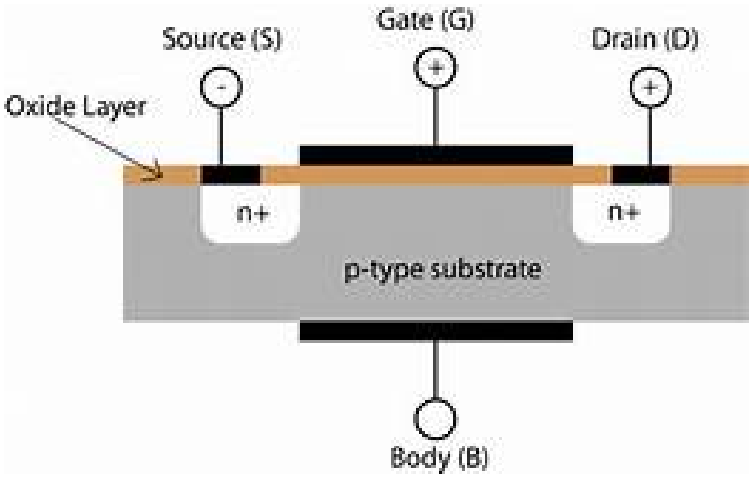
$$\begin{aligned}\triangle U_{BE} &= U_{be}(I_b + \triangle I_b) - U_{be}(I_b) + R_e \triangle I_e \\ \triangle U_{KI} &= -R_c \triangle I_c\end{aligned}$$

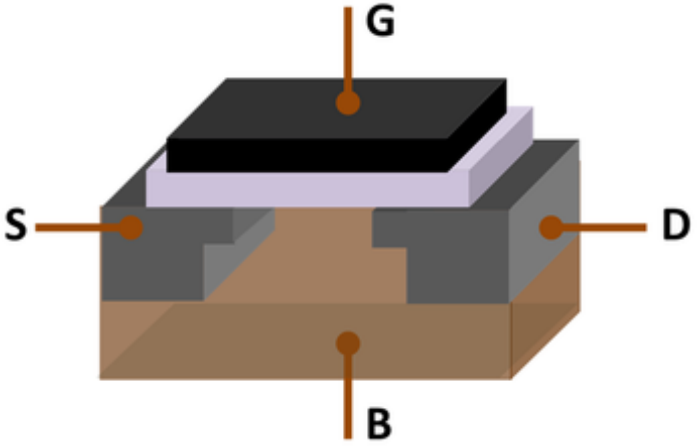
$$\begin{aligned}\triangle U_{BE} &= R_B \triangle I_b + R_e \triangle I_e \\ \triangle U_{KI} &= -R_c \triangle I_c\end{aligned}$$

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

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

FET, MOSFET


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


G
S
D
B