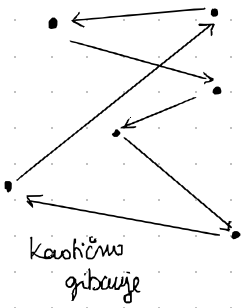
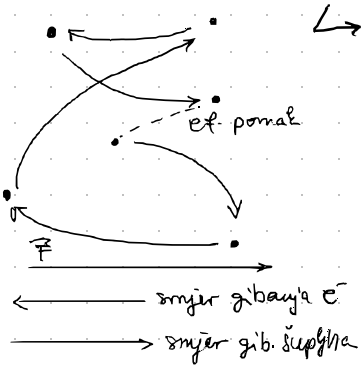
2.3 KRETANJE NOSILACA U POLUVODIČU

Driftna brzina

Elektroni zbog polja dobivaju brzinu
↳ Driftna brzina



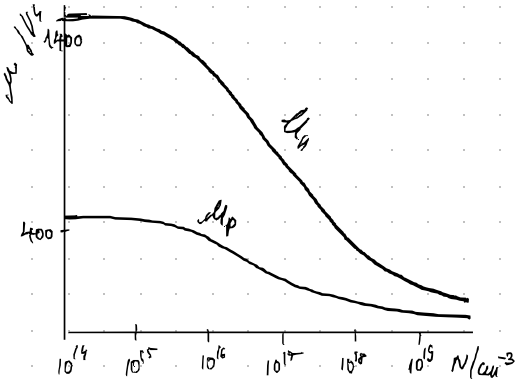


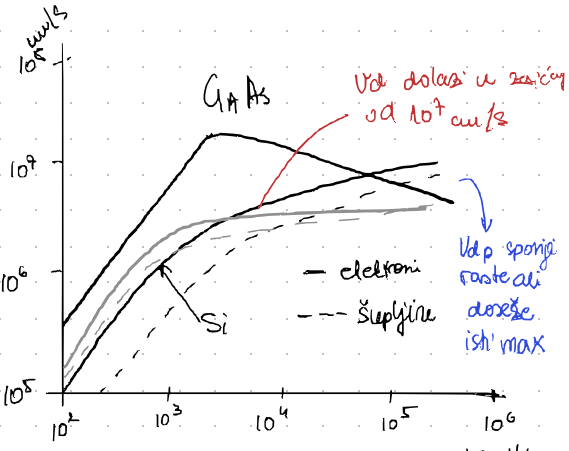
$\vec{v}_{dn} = -\mu_n \vec{F}$

$\vec{v}_{dp} = \mu_p \vec{F}$

v_d - driftna brzina
μ - pokretljivost

Pokretljivost





- malo primjesa → max pokretljivost

→ šupljine imaju manju pokretljivost UVIJEK

Driftna struja

govorimo o polju koje je vektor!

Elektroni: $\vec{v}_{dn}$ n $\vec{J}_{Fn}$

$J_{Fn} = (\text{naboj}) \cdot (\text{brzina}) = -\underbrace{q \cdot n}_{Q} \cdot (\underbrace{-\mu_n}_{\text{pokretljivost}} \cdot \underbrace{\vec{F}}_{\text{polje}})$

naboj — koncentracija e⁻

$\vec{v}_{dn} = -\mu_n \vec{F}$ ——— $\vec{F}$, x

↳ $\vec{J}_{Fn} = q n \mu_n \vec{F}$

Šupljine: q_p $\vec{v}_{dp}$ $\vec{J}_{Fp}$ ——— $\vec{F}$, x

$\vec{v}_{dp} = \mu_p \vec{F}$ $\quad \vec{J}_{Fp} = q p \mu_p \vec{F}$

→ $\vec{J}_F = q(n\mu_n + p\mu_p)\vec{F}$

$\left[A s \frac{1}{cm^3} \frac{cm^2}{Vs} \frac{V}{cm} \right] = \left[A \frac{1}{cm^2} \right]$ gustoća struje J

σ (sigma) (specifična vodljivost)

↳ specifični otpor: $\frac{1}{\sigma}$

$I_F = J_F \cdot S$

- intrinzični: $\sigma_i = q n_i (\mu_n + \mu_p)$

stvarno intrinzičan
$N_A = N_D = 0 \rightarrow \sigma_i = q n_i (\mu_n + \mu_p)$
→ pokretljivost je maksimalna

kvazi intrinzičan
$N_A = N_D = 10^{19} cm^{-3} \rightarrow \sigma_i = q n_i (\mu_n + \mu_p)$
→ N_A i N_D veliki → $N = N_A + N_D = 2 \cdot 10^{19} cm^{-3}$
pokretljivost je puno manja

- n - tip : $\sigma_n = q n \mu_n = q (N_D - N_A) \mu_n$

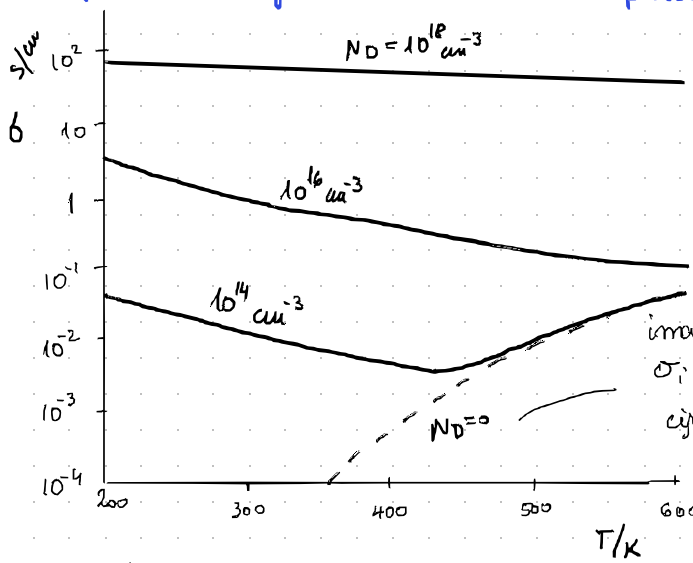
$n >> p$, možemo zanemariti p

- p - tip : $\sigma_p = q p \mu_p = q (N_A - N_D) \mu_p$

← (i $p >> n$)

Specifična vodljivost – ovisnost o temperaturi

$\sigma = q(n\mu_n + p\mu_p)$



$\mu_n > \mu_p$ za cca x3

imamo intrinzični poluvodič

$\sigma_i = q n_i (\mu_n + \mu_p)$ → za intrinzičan cijelo vrijeme raste!

pokretljivost ovisi o T

$\Rightarrow$

$T \uparrow \Rightarrow \mu_n, \mu_p \downarrow$

→ za niske temp: koncentracija N je konstantna (sobna temp)

na višoj temp se brže mijenjati

Primjer 2.6: $\sigma(Si) = ?$ $T_1 = 300K$ $T_2 = 450K$

a) $N_D = 2\times10^{15}\,cm^{15}\,cm^{-3}$ $\mu_{n_1} = 1360\,cm^2/Vs$ $\mu_{n_2} = 625\,cm^2/Vs$

$\mu_{p_1} = 447\,cm^2/Vs$ $\mu_{p_2} = 190\,cm^2/Vs$

$\sigma = q(n\mu_n + p\mu_p)$

$T_1 = 300K \longrightarrow n_i = 1{,}45\times10^{10}\,cm^{-3}$

$N_D >> n_i \longrightarrow n = N_D = 2\times10^{15}\,cm^{-3} \longrightarrow p = \frac{n_i^2}{n} \longrightarrow p = 10^5\,cm^{-3}$

$n >>> p$!

$\sigma = \sigma_n = q_n \cdot n \cdot \mu_n = q N_D \cdot \mu_n \xrightarrow{300K} \sigma_{n_1} = 435\,mS/cm$

$T_2 = 450K \longrightarrow n_i = \ldots = 5.92\times10^{13}\,cm^{-3}$

$N_D >> n_i \longrightarrow n = N_D \longrightarrow p = \frac{n_i^2}{n} \longrightarrow p = 1.75\times10^{12}\,cm^{-3}$ $n >>> p$!

$\sigma = \sigma_{n_2} = q N_D \mu_n \xrightarrow{450} \sigma_{n_2} = 200\,mS/cm$

b) $N_A = 2\times10^{15}\,cm^{-3}$

$T_1 = 300K \longrightarrow n_i = C_1 T^{3/2} \exp\left(-\frac{E_{G0}}{2E_T}\right) = 1{,}45\times10^{10}\,cm^{-3}$

$N_A >> n_i \longrightarrow p = N_D = 2\times10^{15}\,cm^{-3} \longrightarrow n = \frac{n_i^2}{p} \longrightarrow n = 10^5\,cm^{-3} << p$

$\Rightarrow \sigma = \sigma_p = q_p \cdot p \cdot \mu_p = q N_A \cdot \mu_{p_1} \Rightarrow \boxed{\sigma_{p_1} = 143\,mS/cm}$

$T_2 = 450K \longrightarrow n_i = 5{,}92\times10^{13}\,cm^{-3} << N_A \longrightarrow p = N_A \longrightarrow n = 1{,}8\times10^{12}\,cm^{-3} << p$

$\longrightarrow \sigma = \sigma_p = q N_A \mu_{p_2} \Rightarrow \boxed{\sigma_{p_2} = 61\,mS/cm}$

c) $N_D = N_A = 10^{15}\,cm^{-3}$ „kvazi intrinzičan" jer je došlo do rekombinacije pa su „na nuli"

$n = p = n_i \longrightarrow$ intrinzičnost, ALI, pokretljivost je promijenjena

↳ $N = N_D + N_A = 2\times10^{15}\,cm^{-3}$

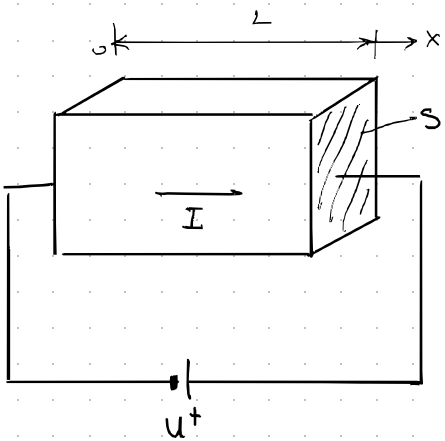
$T_1 = 300K: \quad \sigma = \sigma_i = q n_i (\mu_n + \mu_p)$

$\sigma_{i_1} = 4{,}19\,\mu S/cm$

$T_2 = 450K: \quad \sigma = \sigma_i = 7{,}72\,mS/cm \longrightarrow n_i$ je narastao

Primjer 2.7.) $N_A = 10^6\,cm^{-3}$ $U = 5V$ $T = 300K$

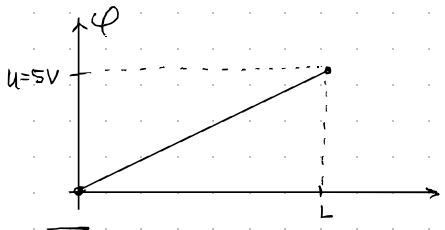
$\mu_n = 1228\,cm^2/Vs$ $\mu_p = 420\,cm^2/Vs$ $L = 50\mu m$ $S = 10\mu m^2$



a) $I = ?$ b) $\sigma_{Si} = ?$ $R = ?$

$L = 50 \cdot 10^{-4}\,cm = 5 \times 10^{-3}\,cm$

$S = 10^{-7}\,cm$



$I = \frac{U}{R}$, $R = \rho \frac{L}{S} = \frac{1}{\sigma} \cdot \frac{L}{S}$

$\vec{J}_F = \vec{J}_{Fn} + \vec{J}_{Fp}$ (jer $N_A \rightarrow p \gg n$)

$\vec{J}_F = \underbrace{q p \mu_p}_{\sigma} \vec{F}_p$

$\sigma_p = q p \mu_p$, $p = ?$

$n_i = C_1 T^{3/2} \exp\left(-\frac{E_{g0}}{2E_T}\right) = 1{,}45 \times 10^{10}\,cm^{-3}$ $N_A >> n_i \rightarrow p = N_A$

$\sigma_p = q N_A \mu_p \rightarrow \sigma_p = 672\,mS/cm$

$\hookrightarrow n = \frac{n_i^2}{p} \rightarrow n = 2{,}1 \times 10^4\,cm^{-3} \ll N_A$

Zato možemo zanemariti J_{Fn}

$\vec{J}_F = \sigma_p \cdot \vec{F}_p$, $F = ?$ $F = \frac{U}{L}$ ili $F = \frac{-\partial\varphi}{\partial x} = -\frac{5V}{L}$

$F = -1000\,V/cm$

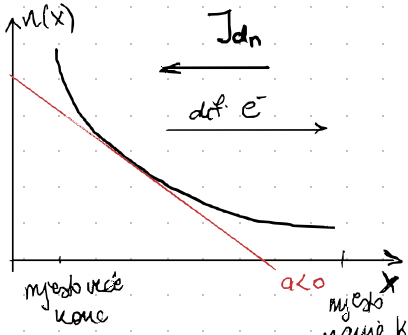
$\rightarrow \vec{J}_F = -672\,A/cm^2$

$\vec{I} = S \cdot \vec{J}_F \rightarrow \boxed{\vec{I} = -67{,}2\,\mu A}$

$R = \frac{1}{\sigma} \cdot \frac{L}{S} = \frac{1}{672 \times 10^{-3}} \cdot \frac{5 \times 10^{-3}}{10^{-7}} \rightarrow \boxed{R = 74{,}4k\,\Omega}$

Difuzijska struja

– nastaje jer nastaje mjesta s različitim koncentrac.



· difuzija nastaje zbog različite koncentracije na x

$\rightarrow J_{Dn} = q D_n \frac{dn(x)}{dx}$ $D_n \rightarrow$ difuzijska konstanta > 0

$\hookleftarrow$ negativna <0 jer tako,

$J_{Dp} = -q D_p \frac{dp(x)}{dx}$ $\hookleftarrow$ ide u istom smjeru

Jednodimenzionalna raspodjela

Einsteinove jednadžbe

$D_n = U_T \mu_n \qquad D_p = U_T \mu_p$

Naponski ekvivalent temperature:

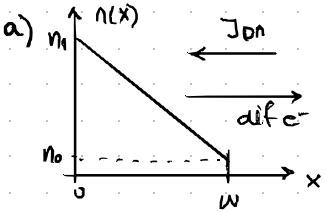
$U_T = \frac{kT}{q} = \frac{T}{11600}\,V \approx E_T$

Primjer 2.8) $x_0 = 0$ $x_1 = 5\mu m$ $x_2 = 10\mu m$ $n_1 = 10^{12}\,cm^{-3}$ $W = 10\mu m$

raspodjela se mijenja prema grafu $n_0 = 10^4\,cm^{-3}$ $a = 5\mu m$

$\mu_n = 1200\,cm^2/Vs$ $T = 300k$

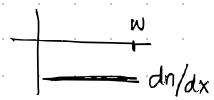
a)



$W = 10^{-3}\,cm$

$a = 5\times10^{-4}\,cm$

$\frac{dn}{dx} = \frac{n_0 - n_1}{W - 0} \approx \frac{-10^{12}}{10^{-3}} = -10^{15}\,cm^{-4}$ ($n_0 \approx 0$)

$J_{Dn} = q D_n \cdot \frac{dn(x)}{dx}$ $\hookrightarrow$  $J_{Dn} = q D_n \cdot \frac{dn}{dx}$

$D_n = U_T \cdot \mu_n = \frac{T}{11600} \cdot 1200\,cm^2$

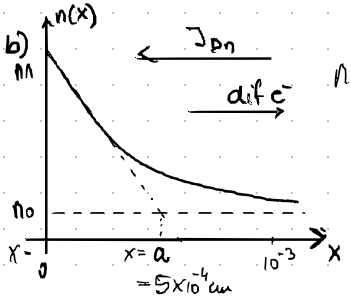
$D_n = 31{,}03$

$J_{Dn} = 1{,}602\times10^{-19} \cdot 31{,}03 \cdot (-10^{15})$

$\boxed{J_{Dn} = -4{,}97\,mA/cm^2}$

to je za sve točke jer je konstantna $\frac{dn}{dx}$

b)



$n(x) = n_0 + (n_1 - n_0)e^{-\frac{x}{a}}$

$J_{Dn} = q D_n \cdot \frac{dn}{dx} = q U_T \cdot \mu_n \cdot \frac{dn}{dx}$

$J_{Dn} = q U_T \mu_n \left(-\frac{n_1 - n_0}{a} e^{-\frac{x}{a}}\right)$

$\frac{dn}{dx} = (n_1 - n_0)\left(\frac{-1}{a}\right) e^{-\frac{x}{a}} = -\frac{n_1 - n_0}{a} e^{-\frac{x}{a}}$

$x = 0\,cm \longrightarrow \boxed{J_{Dn} = -9{,}92\,mA/cm^2}$

$x = 5\times10^{-4}\,cm \longrightarrow \boxed{J_{Dn} = -3{,}64\,mA/cm^2}$

$x = 10^{-3}\,cm \longrightarrow \boxed{J_{Dn} = -1{,}34\,mA/cm^2}$